

# **Investigating crop rotational benefits of a soybean and sugarcane cropping system in South Africa**

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A dissertation submitted in partial fulfilment of the requirements for the degree of

**MASTER OF SCIENCE IN AGRICULTURE (CROP SCIENCE)**

Crop Science

School of Agricultural, Earth and Environmental Sciences

College of Agriculture, Engineering and Science

University of KwaZulu-Natal

Pietermaritzburg

South Africa

November 2013

## Declaration

I, Njabulo Desmah Mkhize, certify that the material reported in this thesis represents my original work, except where acknowledged. I further declare that these results have not otherwise been submitted in any form for any degree or diploma to any university.

Signature \_\_\_\_\_

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I, Professor Albert Thembinkosi Modi supervised the above candidate in the conduct of his dissertation study.

Signature  \_\_\_\_\_

Prof. A.T. Modi

## **Acknowledgements**

My special and most sincere gratitude go to the following:

- My supervisor Prof A.T Modi for his exceptional supervision and support
- Dr. S.D Berry for his patience, guidance and admirable support throughout this study. I know Dr, it was not easy especially last year but thank you and God bless you indeed.
- Ruth Rhodes for her indefatigable effort to this project
- Dr. M.A Smit for mentoring and giving me courage of doing this study.
- Dr. J.A Adtetey for being my interim supervisor
- Thabang Ramogodi for dedicating his time and energy in assisting me with data collection.
- Mcebisi Biyela for adapting rapidly
- Ashiel Juman for his techniques on irrigation
- Qayiso Ntuli for your serenity
- SASRI management for giving me the opportunity of doing this research in their farms.
- SASRI Technical team and SASRI farm workers for their time.

**Dedication**

This work is dedicated to the late Nkosiyezwe Mkhize

## Table of Contents

<b>Declaration</b> .....	<b>2</b>
<b>Acknowledgements</b> .....	<b>3</b>
<b>Dedication</b> .....	<b>4</b>
<b>Table of Contents</b> .....	<b>5</b>
<b>List of figures</b> .....	<b>10</b>
<b>CHAPTER 1</b> .....	<b>20</b>
<b>1.1 Introduction</b> .....	<b>20</b>
1.1.1 Soybean overview .....	23
1.1.2 Growing soybeans in the South African sugar industry .....	24
<b>1.2 Aims, objectives and hypothesis</b> .....	<b>26</b>
<b>1.3 References</b> .....	<b>27</b>
<b>CHAPTER 2</b> .....	<b>30</b>
<b>LITERATURE REVIEW</b> .....	<b>30</b>
<b>2.1 General sugarcane production</b> .....	<b>30</b>
<b>2.2 Sugarcane crop growth requirements and economic value</b> .....	<b>32</b>
2.2.1 Crop origin, structure and propagation .....	32
2.2.2 Factors affecting yield .....	35
2.2.2.1 Water and nutrients.....	35
2.2.2.2 Temperature and photoperiod.....	36
2.2.2.3 Diseases and pests.....	37
<b>2.3 Production systems</b> .....	<b>38</b>

2.3.1 Sugarcane monoculture .....	38
2.3.2 Green manuring .....	39
2.3.3 Crop rotation.....	40
2.3.3.1 Crop rotation effects on sugarcane yields .....	40
2.3.3.2 Crop rotation effects on nitrogen fertilizer use .....	40
2.3.3.3 Crop rotation effects on soil physical characteristics .....	41
2.3.3.4 The effects of crop rotation on pests, diseases and weed control pressures.....	42
2.3.3.5 Constraints to crop rotation.....	42
<b>2.4 References .....</b>	<b>44</b>
<b>CHAPTER 3 .....</b>	<b>51</b>
<b>GENERAL MATERIALS AND METHODS .....</b>	<b>51</b>
3.1 Sites .....	51
3.2 Plant material .....	52
3.2.1 Experimental design.....	54
<b>3. 3 Planting .....</b>	<b>55</b>
3.3.1 Monocropping.....	56
3.3.2 Crop rotation.....	56
3.3.3 Crop growth and development .....	58
3.3.4 Crop yield .....	59
3.3.5 Ratoon crop maintenance (Mount Edgecombe).....	60
3.3.6. Analysis of data.....	60
<b>CHAPTER 4 .....</b>	<b>61</b>
<b>THE EFFECT OF SOYBEAN-SUGARCANE CROP ROTATION ON SUGARCANE GROWTH AND DEVELOPMENT ALONG THE COASTAL REGIONS OF KWAZULU-NATAL.....</b>	<b>61</b>

<b>4.1 Abstract.....</b>	<b>61</b>
<b>4.2 Introduction .....</b>	<b>62</b>
<b>4.3 Materials and methods .....</b>	<b>64</b>
4.3.1 Site.....	64
<b>4.4 Results and discussion .....</b>	<b>64</b>
4.4.1 Soil fertility.....	64
4.4.2 Performance of soybeans .....	65
4.4.3 Sugarcane crop growth and development.....	66
4.4.3.1 Tiller population .....	66
4.4.3.2 Sugarcane height .....	68
4.4.3.3 Sugarcane yield.....	70
4.4.3.4 Ratoon 1 (Sugarcane yield).....	72
4.4.4 Plant mineral nutrient content, chlorophyll and performance indices.....	74
4.4.5 Nematode counts in soil and roots .....	77
<b>4.5 Conclusion.....</b>	<b>79</b>
<b>4.6 References.....</b>	<b>81</b>
<b>THE EFFECT OF A SOYBEAN-SUGARCANE CROP ROTATION ON SUGARCANE GROWTH AND DEVELOPMENT IN THE MIDLANDS REGION OF KWAZULU-NATAL.....</b>	<b>88</b>
<b>5.1 Abstract.....</b>	<b>88</b>
<b>5.2 Introduction .....</b>	<b>89</b>
<b>5.3 Materials and Methods.....</b>	<b>89</b>
<b>5.4 Results and discussion .....</b>	<b>90</b>
5.4.1 Soil fertility.....	90

5.4.2 Performance of soybeans .....	91
5.4.3. Sugarcane crop growth and development.....	91
5.4.3.1 Tiller population .....	91
5.4.3.2 Sugarcane height .....	93
5.4.3.3 Sugarcane yield.....	94
5.4.4 Plant mineral nutrient content, chlorophyll and performance indices.....	97
5.4.5 Nematode counts in soil and roots .....	99
<b>5.5 Conclusion.....</b>	<b>100</b>
<b>5.6 References.....</b>	<b>102</b>
<b>CHAPTER 6.....</b>	<b>107</b>
<b>THE EFFECT OF SOYBEAN-SUGARCANE CROP ROTATION ON SUGARCANE GROWTH AND DEVELOPMENT ALONG THE NORTH COAST REGIONS OF KWAZULU-NATAL.....</b>	<b>107</b>
<b>6.1 Abstract.....</b>	<b>107</b>
<b>6.2 Introduction .....</b>	<b>108</b>
<b>6.3 Materials and methods .....</b>	<b>109</b>
<b>6.4 Results and discussion .....</b>	<b>109</b>
6.4.1 Soil fertility.....	109
6.4.3. Sugarcane crop growth and development.....	111
6.4.3.1Tiller population .....	111
6.4.3.2 Sugarcane yield.....	114
6.4.4 Plant mineral nutrient content, chlorophyll and performance indices.....	117
6.4.5 Nematode counts in soil and roots .....	118
<b>6.5 Conclusion.....</b>	<b>119</b>

<b>6.6 References .....</b>	<b>121</b>
<b>CHAPTER 7 .....</b>	<b>126</b>
<b>A PRELIMINARY ECONOMIC ANALYSIS OF SOYBEAN-SUGARCANE CROP ROTATION SYSTEM.....</b>	<b>126</b>
<b>7.1 Abstract.....</b>	<b>126</b>
<b>7.2. Introduction .....</b>	<b>127</b>
<b>7.3 Farming systems.....</b>	<b>127</b>
<b>7.4 Farm economic analysis: monoculture vs. crop rotation.....</b>	<b>130</b>
<b>7.5 Conclusion.....</b>	<b>133</b>
<b>7.6 References .....</b>	<b>134</b>
<b>CHAPTER 8 .....</b>	<b>139</b>
<b>GENERAL DISCUSSION AND CONCLUSIONS .....</b>	<b>139</b>
<b>8.1 Recommendations .....</b>	<b>142</b>
<b>8.2 References .....</b>	<b>143</b>

## List of figures and tables

<b>Figure 1.1:</b> Cane yield following a soybean break in the Mackay rotation experiment (Garside & Bell, 2007). .....	24
<b>Figure 2.1:</b> World rankings of sugarcane production (Source, FAO, 2012). .....	31
<b>Figure 2.2:</b> Sugarcane plant structure (Van Dillewijn, C., 1952). .....	33
<b>Figure 4.1:</b> Sugarcane tiller population at Mount Edgecombe. Tiller (stalk) population was measured over 4 m in each of the middle two cane rows of each plot. These counts were then calculated into tiller population/ha as shown in this graph above. Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soy-cane 100% N (1) (soybean followed by sugarcane with 100% N); soy-cane 50% N (1) (soybean followed by sugarcane with 50% N); soy-cane 50 % N (2) (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soy-cane 100% N (2) (soybean followed by sugarcane with 100% N). .....	677
<b>Figure 4.2:</b> Sugarcane tiller population at harvest in Mount Edgecombe. Tiller (stalk) population was measured over 4 m in each of the middle two cane rows of each plot. These counts were then calculated into tiller population/ha as shown in this graph above. Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soy-cane 100% N (1) (soybean followed by sugarcane with 100% N); soy-cane 50% N (1) (soybean followed by sugarcane with 50% N); soy-cane 50 % N (2) (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soy-cane 100% N (2) (soybean followed by sugarcane with 100% N). .....	688

**Figure 4.3:** Sugarcane heights at Mount Edgecombe. Height (cm) was measured on 5 plants per plot in each of the middle two cane rows of each plot. Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soy-cane 100% N (1) (soybean followed by sugarcane with 100% N); soy-cane 50% N (1) (soybean followed by sugarcane with 50% N); soy-cane 50 % N (2) (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soy-cane 100% N (2) (soybean followed by sugarcane with 100% N)..... 699

**Figure 4.4** Sugarcane yield (t/ha) in the plant crop at Mount Edgecombe. Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soy-cane 100% N (1) (soybean followed by sugarcane with 100% N); soy-cane 50% N (1) (soybean followed by sugarcane with 50% N); soy-cane 50 % N (2) (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soy-cane 100% N (2) (soybean followed by sugarcane with 100% N). ..... 70

**Figure 4.5:** Estimated recoverable crystal ERC% cane (A) and tons ERC /ha (b) for the plant crop at the Mount Edgecombe trial..... 71

**Figure 4.6:** Sugarcane yield in the first ratoon crop at Mount Edgecombe. Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soy-cane 100% N (1) (soybean followed by sugarcane with 100% N); soy-cane 50% N (1) (soybean followed by sugarcane with 50% N); soy-cane 50 % N (2) (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soy-cane 100% N (2) (soybean followed by sugarcane with 100% N)..... 722

**Figure 4.7:** Estimated recoverable crystal ERC% cane (A) and tons ERC /ha (B) for the plant crop at the Mount Edgecombe trial..... 733

**Figure 4.8:** Sugarcane leaf analysis at 14 leaf growth stage in Mount Edgecombe. Treatments were: cane-cane 100% N (sugarcane followed by sugarcane

with 100% N applied); soy-cane 100% N (1) (soybean followed by sugarcane with 100% N); soy-cane 50% N (1) (soybean followed by sugarcane with 50% N); soy-cane 50 % N (2) (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soy-cane 100% N (2) (soybean followed by sugarcane with 100% N)..... 744

**Figure 4.9:** Chlorophyll Index at mount Edgecombe using a SPAD Logger. Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soy-cane 100% N (1) (soybean followed by sugarcane with 100% N); soy-cane 50% N (1) (soybean followed by sugarcane with 50% N); soy-cane 50 % N (2) (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soy-cane 100% N (2) (soybean followed by sugarcane with 100% N)..... 755

**Figure 4.10:** Crop rotation (left) and Monocrop (right) treatments at harvest..... 766

**Figure 4.11:** Plant Performance Index (using Leaf Area Meter). Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soy-cane 100% N (1) (soybean followed by sugarcane with 100% N); soy-cane 50% N (1) (soybean followed by sugarcane with 50% N); soy-cane 50 % N (2) (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soy-cane 100% N (2) (soybean followed by sugarcane with 100% N). ..... 777

**Figure 4.12:** Nematode populations in the soil at Mount Edgecombe. Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soy-cane 50% N (1) (soybean followed by sugarcane with 50% N); soy-cane 50 % N (2) (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soy-cane 100% N (soybean followed by sugarcane with 100% N)..... 788

**Figure 4.13:** Nematode population in roots at Mount Edgecombe. Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soy-cane 50% N (1) (soybean followed by sugarcane with 50% N); soy-cane 50 % N (2) (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soy-cane 100% N (soybean followed by sugarcane with 100% N)..... 799

**Figure 5.1:** Tiller population at Bruynshill. Tiller (stalk) population was measured over 4 m in each of the middle two cane rows of each plot. These counts were then calculated into tiller population/ha as shown on the graph. Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soy-cane 100% N (1) (soybean followed by sugarcane with 100% N); soy-cane 50% N (1) (soybean followed by sugarcane with 50% N); soy-cane 50 % N (2) (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soy-cane 100% N (2) (soybean followed by sugarcane with 100% N)..... 922

**Figure 5.2:** Tiller population at harvest in Bruynshill. Tiller (stalk) population was measured over 4 m in each of the middle two cane rows of each plot. These counts were then calculated into tiller population/ha. Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soy-cane 100% N (1) (soybean followed by sugarcane with 100% N); soy-cane 50% N (1) (soybean followed by sugarcane with 50% N); soy-cane 50 % N (2) (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soy-cane 100% N (2) (soybean followed by sugarcane with 100% N). ..... 933

**Figure 5.3:** Sugarcane heights at Bruynshill. Height (cm) was measured on 5 plants per plot in each of the middle two cane rows of each plot. Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soy-cane 100% N (1) (soybean followed by sugarcane with 100% N); soy-cane 50% N (1) (soybean followed by sugarcane with 50%

N); soy-cane 50 % N (2) (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soy-cane 100% N (2) (soybean followed by sugarcane with 100% N). ..... 944

**Figure 5.4:** Sugarcane yield in Bruynshill. Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soy-cane 100% N (1) (soybean followed by sugarcane with 100% N); soy-cane 50% N (1) (soybean followed by sugarcane with 50% N); soy-cane 50 % N (2) (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soy-cane 100% N (2) (soybean followed by sugarcane with 100% N). ..... 955

**Figure 5.5:** ERC tons/ha (A) and Estimated recoverable crystal (ERC %) cane (B) at plant crop in Bruynshill trial..... 966

**Figure 5.6:** Sugarcane leaf analysis at 14 leaf growth stage in Bruynshill. Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soy-cane 100% N (1) (soybean followed by sugarcane with 100% N); soy-cane 50% N (1) (soybean followed by sugarcane with 50% N); soy-cane 50 % N (2) (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soy-cane 100% N (2) (soybean followed by sugarcane with 100% N)..... 977

**Figure 5.7:** Chlorophyll Index at Bruynshill using a SPAD Logger. Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soy-cane 100% N (1) (soybean followed by sugarcane with 100% N); soy-cane 50% N (1) (soybean followed by sugarcane with 50% N); soy-cane 50 % N (2) (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soy-cane 100% N (2) (soybean followed by sugarcane with 100% N). ..... 988

**Figure 5.8:** Nematode populations in the soil at Bruynshill. Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soy-cane 50% N (1) (soybean followed by sugarcane with 50% N); soy-cane 50 % N (2) (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soy-cane 100% N (soybean followed by sugarcane with 100% N). ..... 999

**Figure 5.9:** Nematode population in roots at Bruynshill. Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soy-cane 50% N (1) (soybean followed by sugarcane with 50% N); soy-cane 50 % N (2) (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soy-cane 100% N (soybean followed by sugarcane with 100% N). ..... 100100

**Figure 6.1:** Tiller population at Pongola. Tiller (stalk) population was measured over 4 m in each of the middle two cane rows of each plot. These counts were then calculated into tiller population/ha as shown in these graphs above. Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soy-cane 100% N (1) (soybean followed by sugarcane with 100% N); soy-cane 50% N (1) (soybean followed by sugarcane with 50% N); soy-cane 50 % N (2) (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soy-cane 100% N (2) (soybean followed by sugarcane with 100% N)..... 1122

**Figure 6.2:** Tiller population at Pongola. Tiller (stalk) population was measured over 4 m in each of the middle two cane rows of each plot. These counts were then calculated into tiller population/ha as shown in these graphs above. Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soy-cane 100% N (1) (soybean followed by sugarcane with 100% N); soy-cane 50% N (1) (soybean followed by sugarcane with 50% N); soy-cane 50 % N (2) (soybean with fodder

(biomass) removed followed by sugarcane with 50% N); soy-cane 100% N (2) (soybean followed by sugarcane with 100% N)..... 1133

**Figure 6.3:** Sugarcane heights at Pongola. Height (cm) was measured on 5 plants per plot in each of the middle two cane rows of each plot. Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soy-cane 100% N (1) (soybean followed by sugarcane with 100% N); soy-cane 50% N (1) (soybean followed by sugarcane with 50% N); soy-cane 50 % N (2) (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soy-cane 100% N (2) (soybean followed by sugarcane with 100% N). ..... 1144

**Figure 6.4:** Sugarcane yield in Pongola. Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soy-cane 100% N (1) (soybean followed by sugarcane with 100% N); soy-cane 50% N (1) (soybean followed by sugarcane with 50% N); soy-cane 50 % N (2) (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soy-cane 100% N (2) (soybean followed by sugarcane with 100% N). ..... 1155

**Figure 6.5:** Estimated recoverable crystal (ERC %) cane (A) and tons ERC /ha (B) for the plant crop at the Pongola trial..... 1166

**Figure 6.6:** Sugarcane leaf analysis at 14 leaf growth stage in Pongola Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soy-cane 100% N (1) (soybean followed by sugarcane with 100% N); soy-cane 50% N (1) (soybean followed by sugarcane with 50% N); soy-cane 50 % N (2) (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soy-cane 100% N (2) (soybean followed by sugarcane with 100% N). ..... 1177

**Figure 6.7:** Nematode populations in the soil at Pongola. Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soy-cane 50% N (1) (soybean followed by sugarcane with 50% N); soy-cane 50 % N (2) (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soy-cane 100% N (soybean followed by sugarcane with 100% N). ..... 1188

**Figure 6.8:** Nematode population in roots at Pongola. Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soy-cane 50% N (1) (soybean followed by sugarcane with 50% N); soy-cane 50 % N (2) (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soy-cane 100% N (soybean followed by sugarcane with 100% N). ..... 1199

## List of tables

<b>Table 3.1.a:</b> Description of Mount Edgecombe, Bruynshill and Pongola trial sites ...	51
<b>Table 3.1.b:</b> Rainfall in Mount Edgecombe, Bruynshill and Pongola trials.....	522
<b>Table 3.2:</b> Varieties and planting dates in Mount Edgecombe, Bruynshill and Pongola trials.....	533
<b>Table 3.3:</b> Treatments.....	544
<b>Table 4.1:</b> Mount Edgecombe soil analysis results before soybean planting.....	654
<b>Table 4.2:</b> Mount Edgecombe soil analysis results (row and interrow) directly after soybean harvest. ....	655
<b>Table 4.3:</b> Soybeans yield for Mount Edgecombe (ME) at harvest.....	65
<b>Table 5.1:</b> Bruynshill soil analysis results before soybean planting. ....	90
<b>Table 5.2:</b> Bruynshill soil analysis results (row and interrow) at soybean harvest. ...	900
<b>Table 5.3:</b> Soybeans yield for Bruynshill at harvest. ....	911
<b>Table 6.1:</b> Pongola soil analysis results before soybean planting. ....	110
<b>Table 6.2:</b> Pongola soil analysis results (row and interrow) at soybean harvest....	1100
<b>Table 6.3:</b> Soybeans yield for Pongola at harvest. ....	1111

<b>Table 7.1a:</b> Comparison between management inputs associated with the 'old' (monoculture) and 'new' (soybean-cane crop rotation) farming systems. .....	12828
<b>Table 7.1b:</b> Comparison between management inputs associated with the 'old' (monoculture) and 'new' (soybean-cane crop rotation) farming systems. .....	12929
<b>Table 7.2:</b> Economic comparison of two farming systems and tractor hours.....	1312
<b>Table 7.3:</b> Cost of growing cane per hectare (whole farm). .....	13233
<b>Table 7.4:</b> Soybean gross margin.....	13233

# CHAPTER 1

## 1.1 Introduction

South Africa is the largest producer of sugar in Africa and is one of the ten largest sugarcane producers in the world. Sugarcane is an economically important crop and is grown under a wide range of agro-climatic conditions in the eastern regions of the country. These regions are subject to high climatic variability, resulting in large fluctuations in annual production.

Sugarcane (*Saccharum* species hybrids) flourishes under a long and warm summer growing season with a high incidence of radiation and with adequate soil moisture. This needs to be followed by a dry, sunny and fairly cool, but frost-free, winter to promote high sucrose quantities before harvesting (Smith, 1992). Although relatively far south of the equator, some areas in eastern South Africa are well suited for commercial sugarcane production. In these areas sugarcane is produced under a wide range of climatic, agronomic and socio-economic conditions. The South African sugar industry is still a cost competitive producer of approximately 2.2 million tons of sugar per annum and this sugar industry comprises approximately 430 000 ha under cane, with 72% of the annual production cultivated by 2 000 large-scale commercial growers (Meyer, 2007). Forty-eight thousand small-scale subsistence growers cultivate an additional 15% of the country's annual crop, while the remaining 13% is grown by milling companies (Isaacs, 2003). The industry comprises 13 mill supply areas (MSA), which are each characterized by a single mill owned by a milling company. Each sugar mill receives sugarcane from surrounding commercial and small-scale farms that are located in close proximity (approximately 50 km radius on average).

Sugarcane production in South Africa predominantly occurs along the east coast, extending from approximately 25°33'S to 30°93'S and between 29°92'E and 32°32'E, under a diverse range of conditions. Sixty-eight per cent of South Africa's sugarcane is grown within 30 km of the coast in the KwaZulu-Natal province, while

17% of the cane production is found in higher-altitude, frost-prone but high rainfall areas of the KwaZulu-Natal midlands. The remaining 15% is produced under irrigation in the drier areas in the northern KwaZulu-Natal and Mpumalanga provinces (Isaacs, 2003).

From an agronomic point of view, each sugarcane field is uniquely cultivated to suit the specific climatic, soil and socio-economic conditions present. This results in an extended range of management practices over the industry. Approximately 40 cultivars that are specially adapted to South African growing conditions are available. Climate, and especially rainfall, is probably the single most important factor that influences sugarcane production in South Africa. Inter-annual rainfall variability in the sugarcane growing belt ranges from 20% to 35% (Schulze, 1997) and the area is typically subject to relatively frequent severe and wide-spread droughts (e.g. 1983, 1992, 2003 & 2010), occasional flood-producing tropical cyclones (e.g. 1984, 2000) and less frequent mid-latitude cut-off low pressure systems producing excessive heavy rainfalls (e.g. 1987).

The crop is vegetatively propagated through the planting of cane setts (segments of the stalk), each with approximately three to five viable buds, into furrows drawn alongside each other and ranging in spacing from 1 to 1.5 m. In South Africa, planting usually occurs in autumn or spring (preferred due to better soil moisture conditions). Germination, tillering, and stalk elongation rates are highly dependent on genotypic and environmental factors (Smit *et al.*, 2005). The crop is harvested when sucrose accumulation within the stalks reaches a peak, and the time to maturity also varies depending on genotype and growing conditions. In South Africa, sugarcane is harvested any time between 12 and 24 months of age, depending on temperatures (influenced by altitude). In the northern production area (where sugarcane is grown under irrigated conditions) and along the coastal belt, harvesting generally occurs at 12-15 months of age. In the hinterland and midlands regions, harvest age ranges from 15 to 24 months.

In the South African sugarcane industry, harvesting is carried out manually, and involves the cutting of stalks at the base of the plant. As an aid to the harvesting process, the leaf material of the standing crop is usually burnt prior to harvest. Once the first crop ('plant crop') is harvested, buds below the ground are released from apical dominance and subsequently germinate to produce a new crop. This regrowth is termed ratooning. Successive ratoons are characterized by reductions in cane yield (tons cane/ha) due to systemic diseases or physical damage to stools, and the number of ratoons obtained from a single harvest also depends on genotypic and environmental factors. South African sugarcane growers typically harvest approximately 5-10 crops in total (i.e. 1 plant crop and 4-9 ratoon crops) before replanting is necessitated.

Sugarcane growers are remunerated for sugarcane deliveries to the mill through the implementation of the Recoverable Value (RV) payment system, which takes into consideration quality characteristics of the sugarcane.

Worldwide, sugarcane is most commonly grown as a monoculture. Sugarcane monoculture is a major land use on the north and south coasts and even into the midlands of KwaZulu-Natal (Dominy *et al.*, 2001). This production system often leads to a decline in sugarcane yields and depletion of soil fertility (Garside, 1997; Hartemink & Wood, 1998; Haynes & Hamilton, 1999; Shoko *et al.*, 2009). It also makes the crop more susceptible to pests and diseases as the high genetic similarity between plants make them equally vulnerable; especially monocotyledonous weeds which are not easily controlled. Green manure crops can be incorporated into the sugarcane production system to break the continuous cane monoculture and relieve the effects of the sugarcane yield decline syndrome (Garside, 1997), and can also affect nematode dynamics (Pankhurst *et al.*, 1999, Berry & Wiseman, 2003). To add to this, many sugarcane growers are under increasing economic pressure as production costs rise and returns on sugar sold are slim. For this reason, adding an alternative crop before replanting could help to reduce high fertiliser input costs and increase farm revenue.

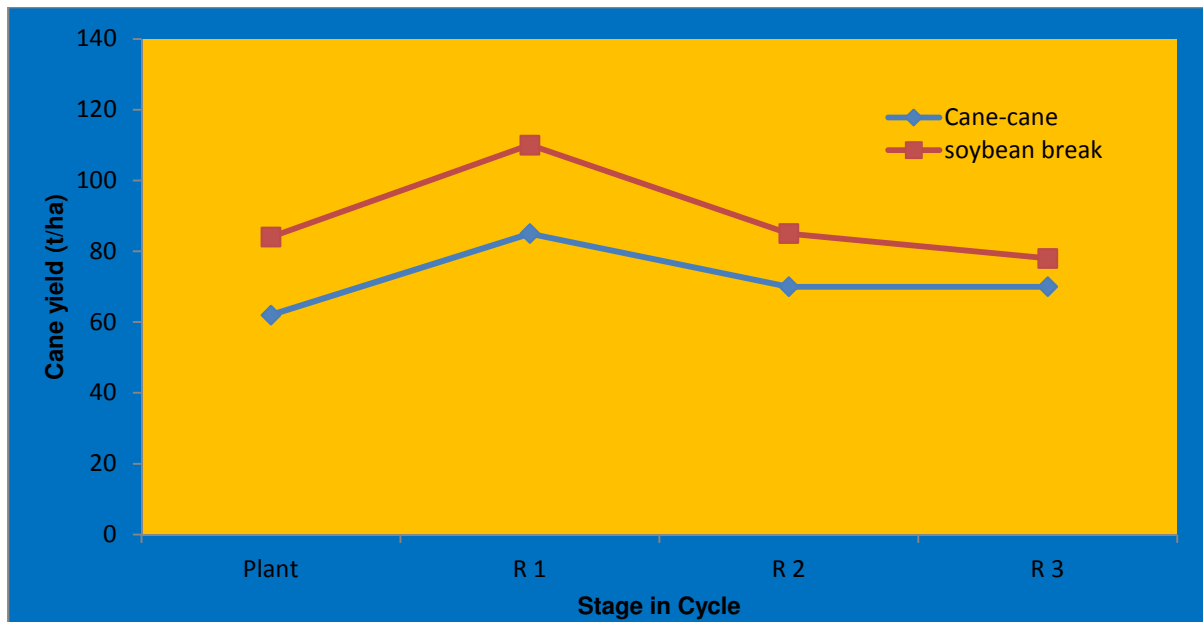
Crop rotation has various advantages which are useful to farm productivity and cash flow improvements. Soybeans show potential as a rotation crop with sugarcane due to its relatively short growth period, and the addition of nitrogen to the soil through atmospheric nitrogen fixation. Soybeans are also reported to reduce the incidence of insect pests and diseases by eliminating hosts and interrupting pest life cycles (Peel, 1998).

### **1.1.1 Soybean overview**

Soybean (*Glycine max* (L.) Merrill) is the world's foremost provider of protein and oil (Singh, 2010; Zarkadas *et al.*, 1993), and the grain and aerial biomass represent a rich source of high-protein food and vegetable oil for human consumption and of protein-rich livestock feed. In South Africa, there is a current annual demand for about 300 000 metric tons of soybeans per annum to produce oil-cake for animal feeds (Singh, 2010). Soybean is also an important ingredient in baby foods and processed foods for the sick and elderly, and is used as a concentrate in livestock fattening programmes. The potential demand greatly exceeds the current local production, and there is an expanding market for consumption as human food.

One of the major features of soybean that makes it an attractive legume crop in many cropping systems is its efficient biological nitrogen fixation in association with *Bradyrhizobium* in the root nodules. Moreover, soybean requires low nitrogen supplies in the form of chemical fertilizers for meeting its own nitrogen requirement. The bacteria on the nodules take nitrogen from the air and fix it into the soil, so that other plants that require nitrogen can use it.

Crop rotation with soybean improved maize yields in South Africa by 30 to 50% (Nel, 2005). It has increased sugarcane yield in Australia by 20 to 30% (Garside *et al.*, 1999), with residual effects lasting for several ratoon crops (Figure 1.1) (Garside & Bell, 2007). Rotation with legumes provides both a source of fixed nitrogen and improvement in soil health (Garside *et al.*, 1998).



**Figure 1.1:** Cane yield following a soybean break in the Mackay rotation experiment (Garside & Bell, 2007).

Soybeans can be used as a cash crop (Garsided & Bell, 2007) and can reduce fertilizer costs due to the crop's ability to fix atmospheric nitrogen (Schroeder *et al.*, 2005). Soybean has been shown to reduce disease incidence, improve moisture conservation under dry land cropping conditions, and improve soil structure and soil nitrogen status (Poggio, 2006). South Africa does not produce enough soybeans to supply current demand and more than a million tonnes are imported annually (AFMA, 2009). Soybeans have not been grown in the South African sugarcane belt as a cash crop and agronomic research is needed in order to characterize cultivar behaviour and cropping risks. The economic feasibility and agronomic benefits of a soybean-sugarcane rotation system have to be tested and demonstrated before the system can be promoted as a best management practice.

### 1.1.2 Growing soybeans in the South African sugar industry

Although the benefits of growing soybeans in rotation with cane have been proven in Australia, they have not been tested in South Africa. A number of differences between the Australian and South African sugarcane production systems and climate make the local testing of this rotation necessary. These include

- Climatic differences (the South African sugar industry is generally much drier than the Australian industry, with approximately 40% less rainfall in the rainfed areas of the South African industry).
- Rainfed sugarcane yields in South Africa are generally lower than those in Australia
- Much of the Australian sugarcane crop is harvested without burning, and it is harvested mechanically. In South Africa, more than 80% of the sugarcane is burnt at harvest, and almost all of it is harvested manually.
- Sugarcane and soybean varieties differ between the two countries.
- In addition, the two industries operate in distinctly different economic climates.

For these reasons, the South African sugarcane growers requested that studies be carried out to test crop rotation with soybeans in the local industry. In addition, neither the growers nor the researchers in the South African sugar industry had previous experience with soybeans, and so this trial was a means to gain some practical knowledge and experience with this crop, in order to be able to advise the growers on soybean growth in future. Field trials would also allow the growers to visit and see the soybeans growing for themselves, in order to gain a firsthand 'feel' for the crop.

## **1.2 Aims, objectives and hypothesis**

This aim of the study was to investigate crop rotation of sugarcane with soybeans at different sites in KwaZulu-Natal, South Africa. The specific objectives of the study were to:

- (1) Evaluate the agronomic performance of the soybean-sugarcane rotation system by characterizing the growth and development response of sugarcane after a soybean break crop in different production regions.
- (2) Carry out an economic analysis of the rotational versus monoculture production systems.
- (3) Analyse and explain the rotation effect in terms of nitrogen fixation, crop health, soil health, weeds and pest implications.

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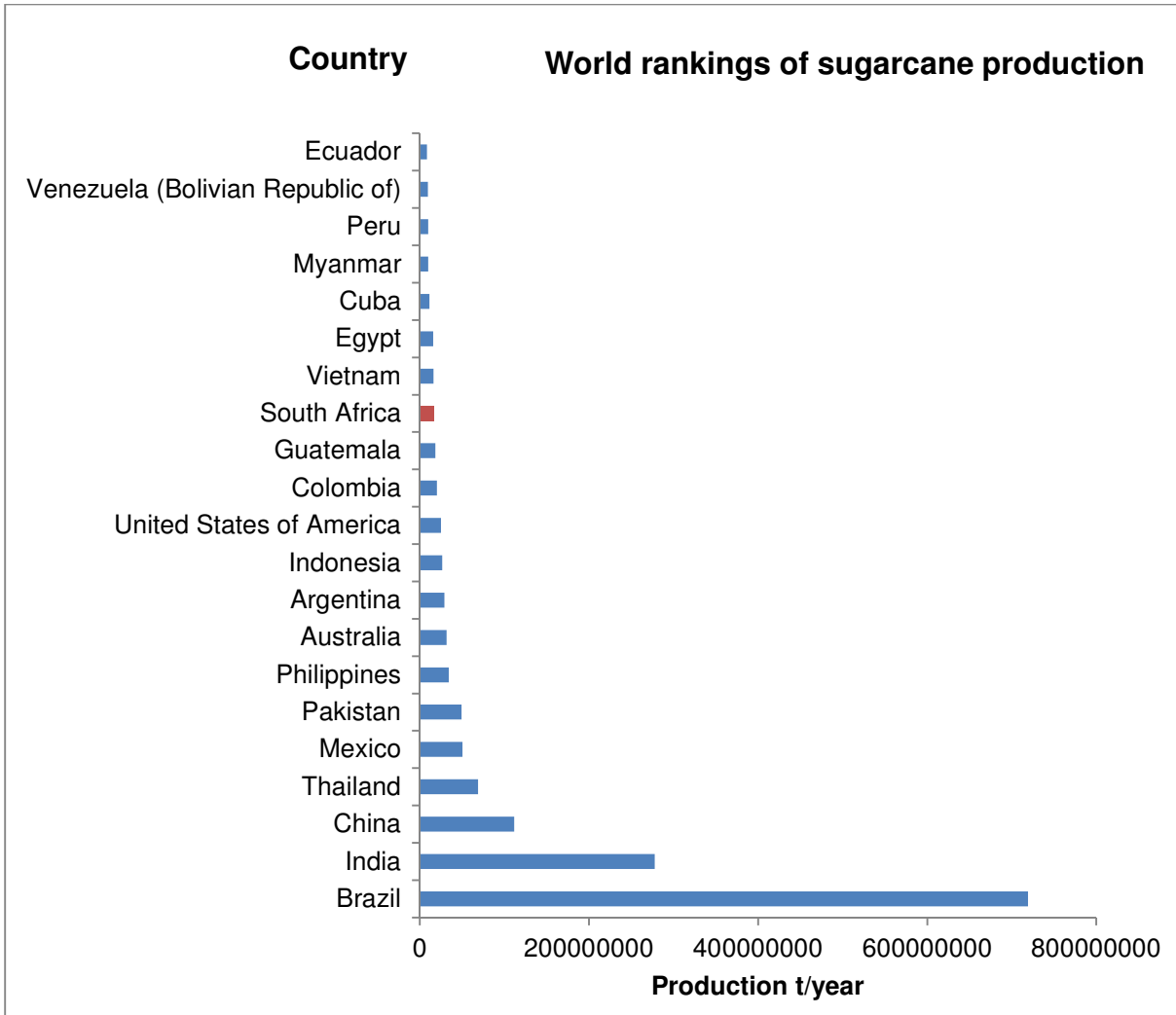
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## CHAPTER 2

### LITERATURE REVIEW

#### 2.1 General sugarcane production

South Africa is among the top 20 countries in terms of sugarcane production rankings (Figure 2.1) in the world and a leading sugarcane producer in Africa. Sugarcane is used for the production of sugar which also adds value to other products. A range of sugar, syrup and downstream products is produced for domestic, preferential, regional and world markets in South Africa. The South African sugar industry has a wide range of brown and refined sugar products to serve both domestic and export markets. Industrial sugar, mainly in refined bulk form, is sold primarily to soft drink, confectionery, canning and re-packing markets. Most of this sugar is sold to markets in other countries too. The refined and brown sugar is pre-packed in paper or plastic of various sizes for direct consumption in domestic markets. It is sold on to retail and wholesale customers and directly to consumers through a wide network of warehouses and distribution channels. A strategic intent of the industry is to optimise the return on every stick of cane. A wide variety of niche, high-value downstream products are produced and marketed from the core commodity products of sugar cane-fibre, sugar and molasses. Downstream products include syrups and ethanol and it is envisaged that ethanol production could significantly contribute to biofuel production in the future.



**Figure 2.1:** World rankings of sugarcane production (Source, FAO, 2012).

Sugarcane does not only provide food and ingredients into the food and beverage industry, but currently, it also supports the energy sector with inputs for the bio energy industry. The production of ethanol and sugarcane bagasse is also coming to the fore in other countries. The main by-products of the sugarcane industry are bagasse and molasses. Bagasse is the raw material in the paper industry; it is also used as one of the growth media for mushroom production. In rural areas green leaves add to the nutritional value in cattle feed (Lewis, 1990; Kneebone & Mason, 1972).

## **2.2 Sugarcane crop growth requirements and economic value**

### **2.2.1 Crop origin, structure and propagation**

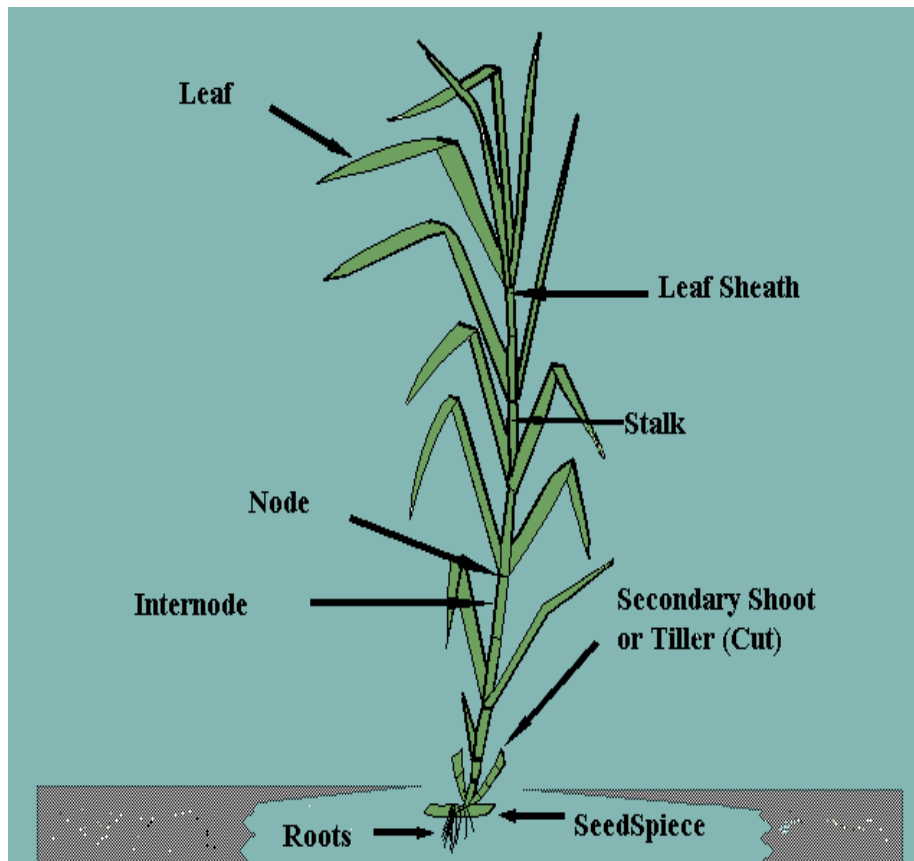
New Guinea is the home of the cultivated form of sugarcane. In ancient times, people migrating from the Indo-China area to New Guinea encountered different types of wild sugarcane. High-fibre forms were used for construction while softer and juicier forms were propagated in gardens for chewing. From about 8000 B.C. people migrated from New Guinea to several Pacific Islands, taking a cultivated form of sugarcane with them. It later reached Indonesia, the Philippines and Northern India. By 400 B.C., crude sugar was developed (Bakker, 1999; Brandes, 1958).

Sugarcane is a giant grass belonging to the genus *Saccharum* and species *officinarum* with many hybrids (Meade, 1963). It is a member of the *Gramineae* family and a crop of major importance, providing about 65% of the sugar produced in the world and serves as a major contributor to the South African economy. The crop generates an income from the sale of sugar and molasses of about R8 billion per annum (Anon, 2011). The zone of sugarcane production characteristically occurs in tropical and sub-tropical latitudes and the crop is grown in soils and climates displaying great variations. South Africa is one of the largest producers and exporters of sugarcane worldwide.

Sugarcane plants have a vigorous and upright growth habit and have a unique ability to store sucrose in their stems. Sucrose is the primary photosynthate and the primary form of carbohydrate storage in sugarcane. Sugarcane plants have an extensive foliar canopy and thickened stems that offer storage and structural benefits.

The sugarcane plant is composed of four principal parts, the root system, the stalk, the leaves and the flower or arrow. However, most of the time, the crop has no arrow, because flowering is day length sensitive (Figure 2.2). Sugarcane has an unbranched stalk that stores the sucrose. The stalk is tall, slender and circular in cross section and bears two rows of leaves. The stalk has distinctive nodes where leaves are attached and the size of the stalk varies with the variety and growing

conditions. Diameter and length of internodes is a function of rate of growth. Sucrose is stored in the internodes. The bud, which is an embryonic shoot consisting of a small stem, bearing miniature outer leaves called scales, is developed from the root band. The internodes vary in shape according to variety and growing conditions.



**Figure 2.2:** Sugarcane plant structure (Van Dillewijn, C., 1952).

Leaves are arranged alternately with a single leaf arising from each node. The upper part of the leaf is the blade and the lower part is the sheath which is attached to the stalk by the basal ring and surrounds the stem completely. Some varieties have spiny hairs on the outside of the sheaths which are shed as the leaf matures. The blade is the expanded part of the leaf.

There are three main types of sugarcane roots. Sett roots, shoot roots and mature roots. Sett roots are temporary and they play a role in nutrient and water uptake at

an early age of the shoot. When the shoots emerge from the ground then shoot roots are formed and their major function is to provide moisture, nutrients and anchorage for the plant. The superficial roots absorb moisture and nutrients. The buttress roots provide stability and the rope systems can penetrate to depths of 3–6 m, where the soil remains moist even during severe drought.

The growing point terminates into a slender arrow bearing a tassel of tiny flowers. The inflorescence (tassel or arrow) is an open branched panicle tapering from the base. The ability of cane to flower and to produce fertile seeds is important for breeding purposes. It is very important to note that fertile seeds are not produced under normal conditions but are produced under controlled photoperiod and temperature in green houses.

Sugarcane is commercially propagated by vegetative means. Seed propagation is only used for breeding purposes as the progeny from true seed differs in character from the parents. Vegetative propagation includes planting of sections of immature stems known as setts, seed cane or seed pieces. Vegetative propagation ensures uniform progeny or off-spring. Apical dominance can inhibit the formation of side branches on undamaged or healthy sugarcane stalk. The stem is cut into 1-5 budded setts. When setts are laid on the ground tops are removed to eliminate apical dominance and reduce the effect of bud growth suppression. The use of hot water treatment (fungicide, 51 °C for 2hrs) to soak setts at planting ensures more uniform germination.

The sugarcane crop has five growth stages, which are germination (emergence), juvenile, early adult, late adult, and flowering. It is very important to monitor these stages, so that the growth performance can be accurately evaluated.

Germination is when the primary shoot develops from setts up to the time of rapid tillering. Germination varies with seed cane quality, variety, node position on stalk and environmental conditions, but in ratoon crops time of cutting appears to be the main factor affecting the growth of new shoots (Van Dillewijn & Clement, 1952).

Disease-free and healthy seed cane must be selected for growing and the planted setts must have three to five buds.

In the juvenile stage, before light energy can be used in photosynthesis it must be intercepted by the leaves, and light not striking any leaves is thus wasted. The time taken to reach full cover, when leaves meet in the inter-row and intercept at least 85% of the incident light, should be as short as possible. To achieve a good, even population of shoots and good growing conditions, adequate water and nutrients are necessary.

### **2.2.2 Factors affecting yield**

Cane yield depends on the number of stalks per hectare, their length, thickness and density, however the yield of sugarcane plant at harvest is largely determined by good management. Sugar yield depends on cane tonnage, sugar content of the cane and on the cane quality. It is important that the cane is harvested at the most suitable time when the economic optimum of recoverable sugar per area is reached. Sugarcane yield (t/ha) and quality are related to the main production factors, namely climate, irrigation water supply, pests and diseases, soil fertility and economic conditions (Schulze, 1997). Mostly pests and diseases, soil fertility and economic conditions are associated with monoculture, so practising a system which can minimize some of these factors will provide useful information for identifying priorities and actions for more efficient production of high quality sugarcane in South Africa. (Singels & Bezuidenhout, 1999).

#### **2.2.2.1 Water and nutrients**

An adequate supply of water is essential for cane growth and a dry period before harvest, is essential for ripening (i.e. the increased storage of sucrose in the stems before harvest) (Van Dillewijn, 1952; Clements, 1980). The crop survives well under normal variations in rainfall around a mean of 1 200 mm/annum. Sugarcane is moderately resistant to drought, but severe water limitations affect growth and yield. Rainfall is the main factor limiting the growth of sugarcane in South Africa, and sugar

yields are determined by the temperatures and radiation experienced by the crop (Clement, 1980). The volume of leaf material remains fairly constant during the early adult stage and stalks elongate rapidly provided that water and nutrients are readily available.

Nutrients play a major role in physiological processes, for example, nitrogen (N) increases yield in sugarcane and improves assimilation rate of leaves at all stages and improves respiration during the early periods of growth (Singh, 1941a). The role of nitrogen in sugarcane includes improving vegetative activities (increased height, leaf number, and girth of a stem) and physiological performance (dry weight, respiration and assimilation rate and chlorophyll content) (Singh & Lal, 1940). Nitrogen assists sugarcane by stabilizing the chlorophyll content of the leaves and so increase yield (Jangpromma, 2010).

#### 2.2.2.2 Temperature and photoperiod

Floral initiation only takes place in sugarcane when day length is approximately 12.5 hours. In South Africa, this occurs between the 5<sup>th</sup> and 17<sup>th</sup> of March. The flowering stimulus is produced in the spindle leaves and the removal of these at the critical time will prevent flowering. Flowers usually emerge from June onwards and are most obvious in July and August. In addition to day length, the plant and weather conditions must be suitable for flowering to take place. Stalks must have several mature internodes; night temperatures must be about 21°C; and there must be no moisture or physiological stress. When a flower is produced by the stalk, the normal physiological processes are altered and vegetative growth stops. This causes all existing tissues to age; leaves gradually lose their photosynthetic capacity and senesce while the stem continues to store sucrose until photosynthesis in the leaves stops. After this, the sucrose content in the stalk starts to decline. This ageing process is affected by climate, and high temperatures increase the rate of change.

Sugarcane is a tropical crop and is grown in subtropical areas, between 15°S and 30°S latitudes. It grows best at mean daily temperatures of 30-35°C (Clement, 1980).

Lower temperatures course slower rates of germination, poorer rates of stalk elongation, and lower yields. Temperature and radiation are directly correlated with one another and these weather factors influence the time taken for plants to reach their full growth potential. This is why a much longer period of time is required to achieve a given yield in the Midlands area than at the coast in KwaZulu-Natal. Temperature has an effect on stalk elongation, where a stalk length of, say, 200 cm is reached much sooner at optimal growth temperatures of 26°C and 30°C (Clement, 1980).

Sugarcane can be grown at the temperature of 30°C, with adequate moisture and high incident solar radiation (Clement, 1980). Usually the plant ripens when temperatures are between 10 and 20°C, frost free or when the crop experiences a mild water stress. The interception of sunlight must be high. In South Africa, these conditions prevail in May to July. This causes sucrose content to peak in August to mid-October. Harvesting and milling of the cane can take place on both sides of the peak (starting in March/April and ending in December/January) (Van Dillewijn 1952). This results in an extended range of management practices over the industry. Approximately 40 cultivars that are specially adapted to South African growing conditions are available. Sugarcane is harvested at ages ranging from 12 to 24 months, depending on climatic conditions, and is cultivated under different irrigation and rainfed scenarios.

#### 2.2.2.3 Diseases and pests

There are many diseases and pests (e.g. Rust (*Puccinia melanocephala*), mosaic, smut (*Ustilago Scitaminea*), yellow leaf disease, red rot disease (*Colletotrichum Falcatum*), pokkahboeng (*Gibberella fujikuroi*), ratoon stunting disease (RSD) (*Leifsonia xyli subsp*) and eldana (*saccharinastem borer*) affecting sugarcane. in different ways. Most of these pests and diseases are dependent upon the environmental conditions, quality of setts and handling of the plants e.g. exposing sugarcane plants to stress either from water stress, temperature, pH, and soil nutrition. Hail damage can cause cane plants to be easily susceptible to diseases

due to the bruised stalks and broken leaves, giving the diseases access to the damaged setts. Rust, mosaic, smut, RSD and eldana are the most detrimental pests and disease in the South African sugar industry. It is very important for a farmer to prevent and control such pests and diseases to avoid losses.

## **2.3 Production systems**

### **2.3.1 Sugarcane monoculture**

Monoculture is an agricultural practice of growing the same crop year after year on the same land without alternating with other crops. Monoculture is controversial as it is seen to be a solution to the problems of economic demand, environmental and political stability; however it is also associated with yield decline. The monocropping system is also heavily dependent on use of pesticides and artificial fertilizers. It also makes the crop more susceptible to pests and diseases as the high genetic similarity between plants make them equally vulnerable; especially monocot weeds which are not easily controlled.

Sugarcane in South Africa is grown as a perennial crop with three to five annual harvests made from a single vegetatively propagated planting. Mono-cropping of sugarcane is a general practice in South Africa. This production system leads to a decline in sugarcane yields and depletion of soil fertility (Shoko *et al.*, 2009). Yield decline is a complex issue caused by a number of factors being out of balance in the sugarcane cropping system. Yield decline can be defined as 'the loss of productive capacity of sugarcane growing soils under long term mono-cropping' (Garside *et al.*, 1997a). Soil degradation can also be the result of long term sugarcane monoculture since crop rotation is not practised, which can result in soil not being replenished with essential nutrients. The soil becomes dry and begins to erode very easily. The monoculture system of sugarcane production also affects other nutrients such as phosphorus and potassium, and also exchangeable cations, pH and organic matter levels in the soil (Alabanet *et al.*, 1990; Meyer & van Antwerpen, 2001). A cane yield of 100 t/ha removed 120 kg N/ha, 133 kg P/ha and 125kg K /ha (Sundara, 1982, Anon 2003a). Conversely, soybeans have been shown to sustain the ideal soil pH for

sugarcane production in Zimbabwe (Shoko *et al.*, 2005). Monoculture can also cause a build-up of pests and diseases, increase the spread of a wide range of grass weeds, and tends to increase parasitic nematodes in sugarcane (Sparkes & Charleston, 2003). However, the monoculture cycle can be broken by practising crop rotation (Capriel *et al.*, 1992) and soil organic matter can be stabilised or increased through green manuring, minimum tillage, and green cane harvesting and spreading of crop residues.

It is known that the issue of sugarcane yield reduction due to monoculture prompted researchers in Australia to explore the benefits of crop rotation and fallow cropping in their sugar industry (Bell *et al.*, 1998; Garside *et al.*, 1999, 2000a, 2001, 2002a).

### **2.3.2 Green manuring**

Green manuring is the practice of growing an alternative crop or plant species between planting cycles of the primary agricultural crop. The green manure crop is not harvested, but is instead returned to the soil to improve soil health and recycle organic matter and nutrients. Green manuring involves growing a crop that will be worked into the soil later to reduce hardpans. Almost any crop can be used for green manuring, but legumes are preferred because of their ability to fix nitrogen from the air. Green manuring with legumes (e.g. peas, clover, lentils and soybean) is called legume green manuring. Green manuring is gaining popularity as a method that successfully improves soil productivity (Sparkes & Charleston 2003). Adding crop residues to the soil helps to maintain soil organic matter, earthworms and micro-organisms. The increase in soil organic matter increases nutrient availability and improves the physical qualities of soil such as water infiltration, moisture storage capacity, aggregate stability, and resistance to erosion (Peel, 1998). Green manures cover the ground well and compete with weeds for water, nutrients, space and light. Green manures also reduce the build-up of pest populations and diseases. In particular, green manures can be used to control root-knot nematodes and root rot fungal pathogens, reducing the need to use toxic chemicals for soil fumigation (Bell, 2001).

Soybean can be used as a break crop, and as a green manuring-growing crop, since soybean can be returned to the soil as green mulch (Rhodes, 2006). Preliminary results suggest that a green manure fallow duration of at least six to twelve months is beneficial in terms of soil health compared to a three month fallow on sugarcane (Rhodes *et al.*, 2009).

Legume green manuring is a management tool worth considering. The main benefit of using a legume as a green manure is that legumes fix nitrogen from the atmosphere and convert it into a form that is available to other plants. Using soybean as a green manure can also be beneficial for mulching, composting and feeding to livestock.

### **2.3.3 Crop rotation**

Crop rotation is an effective cultural practice of growing different crops of different species and families after each other in successive seasons on the same area to manage production, improve crop quality, reduce the build-up of diseases, reduce weed pressure and improve soil fertility (Peel, 1998).

#### **2.3.3.1 Crop rotation effects on sugarcane yields**

Sugarcane production is characterised by a break after the final harvest where land is rested and during that time of fallow a short season crop should be planted. Breaking monocropping of sugarcane through the introduction of suitable break crops in Australia increased cane yields by 15-20% in trials (Sparkes & Charleston, 2003). Break crops that were used consisted of pastures, peanuts, maize and soybeans, but the best results in terms of yield increase with short season crops was achieved with soybeans (Charleston *et al.*, 2000).

#### **2.3.3.2 Crop rotation effects on nitrogen fertilizer use**

Crop rotation has various advantages which are useful to farm productivity and cash flow improvements. Soybean does not require additional nitrogen fertilizer during planting. Fixed nitrogen provides enough nitrogen for plant growth and development. According to Israel (1981) the nitrogen fixation process becomes active

approximately four to five weeks after germination, thus seedlings are primarily dependent upon seed reserves for nitrogen. It was found by Naegle, (2002) that application of nitrogen fertilizer on soybean does not have any significant influence on growth and development. Rotation of sugarcane with soybeans can be beneficial since soybeans can fix up to 300kg N/ha (Giller *et al*, 1997; Viator & Griffin, 2001), relieve the build-up of diseases, suppress grass weeds, reduce plant-parasitic nematodes as well as increase the free-living nematodes which result in improvement in biological activity in the soil (Sparkes & Charleston, 2003). Rotation with legume crops increases the amount of nitrogen in the soil since legumes have the potential to fix nitrogen for the next crop and reduce the incidence of insect and disease pests by eliminating hosts and interrupting pest life cycles; and rotations prevent pest movement from one field to another (Peel, 1998).

Knowing that nitrogen fertilizer is a substantial cost component of the sugarcane cropping system, any approach that can maximise the availability of legume nitrogen and reduce the need for nitrogen fertilizer should be encouraged (Chokowo *et al.*, 2003). Nitrogen fertilizers are vulnerable to leaching, and may contribute to environmental problems. These problems are of particular concern since pollution interferes with ground water and the release of high emissions of nitrous oxide (Thorburn *et al.*, 2003) whereas the use of organic nitrogen sources can help to improve the organic nitrogen and nutrient content of the soil (Shoko *et al.*, 2009).

### **2.3.3.3 Crop rotation effects on soil physical characteristics**

It has been demonstrated that crop rotation also prevents soil depletion, maintains soil fertility and organic matter and reduces soil erosion. Crop rotation can also enhance moisture management in the soil. Rotation also assists producers to use conservation tillage successfully. Another benefit of crop rotation is that it contributes to yield enhancement by improving physical properties such as tilth and soil density (Peel, 1998). Crop rotation reduces reliance on synthetic chemicals, which reduces the risk of leaching herbicides and fertilizer.

#### **2.3.3.4 The effects of crop rotation on pests, diseases and weed control pressures**

Monoculture can cause a build up of diseases, a wide range of grass weeds and tend to increase parasitic nematodes in sugarcane. This monoculture cycle can only be broken by practising crop rotation (Capriel et al., 1992). Ideally soybean can be used, since it has been shown by Charleston & Garside, 2000 that soybean can reduce disease incidence (soil borne diseases and nematodes). Some pests overwinter in residue and soil survive to harm the next crop if it is susceptible. Non-susceptible crops can cause the pest to die out without a host or move elsewhere. Rotation will have an effect on the weeds in a system. Increasing the complexity of a rotation can reduce weeds because of the varying cultural practices used with different crops and differences in life cycles or grow habits.

#### **2.3.3.5 Constraints to crop rotation**

There are various constraints in implementing crop rotation successfully. Firstly, technology can be the barrier for some farmers due to the fact that it is very hard to adapt to change. Planting a new crop is always challenging and diversifying also has an influence on the market outlet. The most important part is to have a constructive crop rotation plan because errors do take place when practising crop rotation. A risk is that there is a possibility of carry-over of herbicides from one crop to a succeeding crop. Management skills and information can be a limiting factor in practising crop rotation. New implements to match the current crop can also be problematic to have an operative crop rotation system.

Addressing these constraints is necessary to farmers in making a proper decision of practising crop rotation or not. One of the major tasks is that it is very difficult for farmers to shift from a well-known crop to an unknown crop because challenges which will arise from a new crop will reduce farm productivity. Moreover shifting from a well-known market to a new market can also be restrictive at times. Working with a new crop can be challenging especially in terms of new technology, crop management skills, new implements for planting and harvesting of a labour intensive crop like soybeans. Weed management is not an issue during fallow period but by

introducing soybeans, broadleaf weeds would be suppressed from the field. Fallow crops are often considered in isolation, not as part of the farming system. However, many farmers may realize that investing money to a fallow crop can pay dividends, with no nitrogen topdressing required for planting cane, less expensive weed control in the sugarcane crop as well as soil health benefits and the opportunity to reduce tillage in the cane crop (Sparkes & Charleston, 2003).

Despite the well-documented benefits of crop rotation with soybeans (Garside *et al.*, 1998; Garside *et al.*, 1999), the crop has not traditionally been grown in the South African sugar industry. These reported benefits have not been tested in South Africa, where there are different climatic conditions, pest and disease pressures, and different sugarcane and soybean varieties. It is likely that South African conditions and varieties could result in yield responses that are different to the Australians. Whereas, the Australian research has documented cases of increased cane yield following break crops (Garside *et al.*, 1999), mainly due to a healthier plant crop, the different yield components have not been quantified. Quantifying yield components can assist in determining the effect of crop rotation vs. monoculture.

## 2.4 References

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## CHAPTER 3

### GENERAL MATERIALS AND METHODS

#### 3.1 Sites

The three sites selected for this study were Mount Edgecombe, Bruynshill and Pongola (all sites were within close proximity to automatic weather stations for scheduling irrigation). These sites were chosen to represent different environmental conditions within the sugar industry, with the aim of obtaining a clear indication of the performance of crop rotation in sugarcane across contrasting conditions. Table 3.1.a gives a description of the trials and Table 3.1.b shows rainfall for each trial site. A four months rainfall was measured during soybean production, twelve and twenty four months rainfall was measured during sugarcane production.

Table 3.1a: Description of Mount Edgecombe, Bruynshill and Pongola trial sites

	Mt Edgecombe	Bruyns Hill	Pongola
GP co-ordinates	29 42' 16" S - 31 02' 47" E	29 25' 22" S - 30 40' 56" E	27 25' 04" S – 31 35' 27" E
Soil Organic Matter %	1.6	3.5	1.6
Soil clay%	22	21	26
Soil pH (water)	5.9	4.5	6.0
Mean Annual Maximum temperature (°C)	30	28	31
Mean Annual Minimum temperature (°C)	18	16	17

Table 3.1.b: Rainfall in Mount Edgecombe, Bruynshill and Pongola trials

	<b>Mt Edgecombe</b>	<b>Bruyns Hill</b>	<b>Pongola</b>
Actual rainfall (mm) in 4 months	585	617	425
LTM rainfall (mm) in 4 months	649	530	533
Actual rainfall (mm) in 12 months	927	-	575
LTM rainfall (mm) in 12 months	1000		693
Actual rainfall (mm) in 24 months	-	1897	-
LTM rainfall (mm) in 24 months	-	1523	-

### 3.2 Plant material

Soybean cultivar A5409RG was purchased from Pannar seed (Greytown). The cultivar was selected because of its adaptive capacity in coastal areas. This soybean cultivar is round-up ready allowing the use of glyphosphate to control weeds. Sugarcane cultivar NCo376 was collected from South African Sugarcane Research Institute (SASRI) in Mt Edgecombe. The cultivar was selected because it has been used as a reference for many years in the sugarcane breeding programme at SASRI. NCo376 is considered to be a hardy, productive cultivar, and the wealth of knowledge available on this variety would facilitate its usefulness for crop modelling

if necessary. The planting and harvesting dates for each crop are shown in Table 3.2 below.

Table 3.2: Varieties and planting dates in Mount Edgecombe, Bruynshill and Pongola trials

	Mt Edgecombe	Bruyns Hill	Pongola
Sugarcane variety	NCo376	NCo376	NCo376
Source of sugarcane	SASRI variety	SASRI variety	SASRI variety
Row spacing	1.0 m	1.0 m	1.4 m
Rows per plot	7 rows	7 rows	7 rows
Row length	9 m	9 m	9 m
Plot size	81 m <sup>2</sup>	81 m <sup>2</sup>	81 m <sup>2</sup>
Soybean cultivar	A5409RG	A5409RG	A5409RG
Soybeans and/or sugarcane planting date	19-Nov-09	07-Nov-09	16-Nov-10
Soybean harvest date and/or sugarcane removal	19-Apr-10	26-Apr-10	11-Apr-11
Sugarcane planting date	21-Apr-10	29-Apr-10	13-Apr-11
Sugarcane harvest date	16-May-11	11-Apr-12	23-Apr-12
sugarcane (ratoon 1) harvest date	11-Jun-12		

### 3.2.1 Experimental design

The trials had five treatments and each treatment was replicated six times. A stratified random block design was used for trial layout. Details of the treatments are given in Table 3.3

Table 3.3: Treatments.

<b>T1:</b> Sugarcane planted after sugarcane (FAS recommendations)	<b>Cane-cane 100%N</b>
<b>T2:</b> Sugarcane planted after soybeans grown to harvest maturity (FAS recommendations)	<b>Soya-cane 100%N</b>
<b>T3:</b> Sugarcane planted after soybeans grown to harvest maturity (standard FAS P & K; 50% of FAS-N)	<b>Soya-cane 50%N</b>
<b>T4:</b> Sugarcane planted after soybeans with fodder removed in the early pod fill stage (standard FAS P & K; 50% of FAS-N)	<b>Soya-cane 50%N</b>
<b>T5:</b> Sugarcane planted after soybeans managed as a green manure crop. (standard FAS P and K; 100% of FAS-N)	<b>Soya-cane 100%N</b>

\*Note: for the trials at Mt Edgecombe and Bruynshill, Treatment 2 was Soya-cane with 100%N. For the Pongola trial, Treatment 2 was Soya-Cane with 0%N.

For treatments 2 to 5 (crop rotation treatments), soybeans were planted and harvested; sugarcane was then planted with different levels of nitrogen fertiliser. For treatment 1 (monocrop), sugarcane was planted at the same time as the soybeans in the other treatments; the sugarcane was then killed with glyphosate (8 L/ha) at the time of soybean harvest. Sugarcane was then planted into all treatment plots, to facilitate comparison between the cane crops in each treatment.

### 3. 3 Planting

Soil samples were collected before planting using a screw auger, at 20 cm depths. Ten points were identified at each trial site, with five borings collected at each point. The 0-20 cm and 20-40 cm sample depths from the five borings were collected at each of the ten points. Soils from each depth were mixed thoroughly, decanted into soil sample boxes, labelled and sent to SASRI's Fertilizer Advisory Service (FAS) for analysis of the nutritional status of the soil. Soil samples were collected on 29 October 2009 at Mount Edgecombe, 12 October 2009 at Bruynshill, and 25 October 2010 In Pongola.

At Mount Edgecombe, 3 t/ha calmasil (a calcium-silicate slag) was broadcast by hand and incorporated into the soil with a disc harrow on the 11<sup>th</sup> of November 2009. Calmasil was similarly applied at 3 t/ha on the 4<sup>th</sup> of November 2009 at Bruynshill and on the 3<sup>rd</sup> of November 2010 at Pongola. During soil preparation a mouldboard plough was used, followed by a disc harrow to break down the clods. After preparing a fine seedbed, a Bramley planter was used to plant the soybeans with a row spacing of 75 cm, seeding depth of 25 mm and seeding density of 350,000/ha. Before planting, the soybean seed was inoculated with *Bradyrhizobiumjaponicum* and treated with sodium molybdate powder (35 g per 50 kg of seed). Inoculation of soybean was carried out in order for the soybeans to fix nitrogen optimally. The amount of fertilizer which was applied was based on the soil results from FAS. In Mount Edgecombe, potassium chloride (KCl) was broadcast by hand at a rate of 150 kg per ha and 35 kg per ha of superphosphate (10.5 % P) was also broadcast by hand. In Bruynshill, potassium chloride (KCl, at a rate of 50 kg per ha) and superphosphate (10.5 % P, at a rate of 20 kg per ha) was broadcast by hand. Whereas in Pongola, potassium chloride (KCl) was broadcast by hand at a rate of 150 kg per ha and 100 kg per ha of superphosphate was also broadcast by hand.

In the sugarcane monocropping plots, sugarcane was planted at the same time as the soybeans. Furrows were opened and two sticks of sugarcane ('seed cane') were laid next to each other, end to end, top to tail, for the length of each furrow. Eight t/ha of seed cane was planted and the seed cane cut into smaller pieces with a cane

knife. Urea (100kg N/ha) was applied in furrows (0.196 kg N/row) and furrows were then closed with soil. Nine sugarcane rows were planted into each monocropped plot at Bruyns Hill (1.0 m row spacing), seven rows at Mount Edgecombe (1.0 m row spacing) and 6 rows at Pongola (1.4 m row spacing), according to the commercial row spacing norms at each trial site.

### **3.3.1 Monocropping**

The sugarcane which was grown together with the soybeans was killed at the time of the soybean harvest, i.e. at four months of age. The sugarcane was sprayed with Roundup® (Monsanto) at 8 L/ha. After two weeks, the dead cane was cut down and removed from the field. It was noted that glyphosate in the soil is strongly adsorbed to colloids, and its leachability is notably low. New furrows were drawn in between the old cane rows, and a new crop of sugarcane (variety NCo376, 8 t/ha seed cane) was planted so that the sugarcane in all plots, monocrop and crop rotation, had the same amount of time to grow. This allowed a proper comparison of the monocropping and crop rotation systems.

### **3.3.2 Crop rotation**

During soybean growth, weed control was done at 30 and 60 days after planting. Roundup® was applied at a rate of 263 ml in 15 l of water (3.5 l/ha) and 47 ml in 15 l of water (0.25l/ha). Metribuzin+188ml (1.0 l/Ha) Falcon in 15L of water and Velocity at a rate of 69ml (2l/ha) were also applied.

Immoboost® and Fastac® were applied after 95 days at a rate of 300 ml/ha and 0.1 l/ha, respectively, for insect control. Soybean rust was controlled with Punch Extra at a rate of 0.6 l/ha. Two applications were made at each trial site, in mid February and early March.

In treatment 4, all soybean aerial biomass was cut and removed from the plots at the R6 growth (pod-filling) stage. This treatment was included in the trials in order to simulate a livestock browsing scenario. The soybeans in treatments 2 and 3 were harvested by hand at four months. Soybeans were cut at the base and weighed using a tripod. The only available threshing machine was unreliable, so soybean plants were placed between two plastic sheets and crushed by the wheels of a tractor. The seeds and chaff were separated and grain yield determined. Treatment 5 was left standing in the field to simulate a green manuring scenario.

Furrows were opened in all plots at the sugarcane row spacings described above, and double sticks of seed cane placed into each. Seed cane was cut with cane knives to suppress apical dominance. In the 100% N treatments (treatments 1, 2 and 5) at Mount Edgecombe, 1.761 kg/plot (100 kg/ha) Urea was applied in the furrow, while in the 50% N treatments (3 and 4), Urea was applied at 0.880 kg/plot (50 kg/ha) in the furrows. All five treatments received the same amount of superphosphate, 20 kg/ha or 1.543 kg/plot. After the application of fertilizer, furrows were closed with soil using hoes and drip irrigation was installed. The date of sugarcane planting at Mount Edgecombe was the 21<sup>st</sup> of April 2010.

At Bruynshill, sugarcane was planted on the 29<sup>th</sup> of April 2010. Treatment 1, 2 and 5 (100% N) received 1.761 kg/plot (100 kg/ha) Urea, while treatment 3 and 4 received 0.880 kg/plot (50 kg/ha) Urea at planting. All five treatments received the same amount of superphosphate at the rate of 1.543 kg/plot (20 kg/ha) and 1.215 kg/plot (75 kg/ha) of potassium chloride at planting.

At Pongola, sugarcane was planted on the 13<sup>th</sup> of April 2011. Treatment 2 was treated differently in Pongola than in Mt Edgecombe and Bryunshill, to allow proper comparison between the treatments and for possible future use for modelling purposes. Treatment 1 (100% N) and treatment 5 received 3.579 kg/plot (140 kg/ha) Urea while treatments 2 did not receive Urea (0% N) and treatment 3 and 4 received 1.790 kg/plot (70 kg/ha) Urea at planting. All five treatments received the same

amount of superphosphate at a rate of 2.240 kg/plot (40 kg/ha) and 2.352 kg/plot (200 kg/ha) of potassium chloride at planting.

In the sugarcane crop, weeds were controlled with 47 ml (0.25 L/ha) Metribuzin and 188 mL (1.0 l/ha) Falcon in 15 L of water. Herbicides were applied in mid January.

### **3.3.3 Crop growth and development**

Soybean phenology was recorded by taking into consideration the date of emergence, flowering, physiological and harvest maturity. Stalk height at flowering and harvest maturity were quantified by measuring five plants per plot; the soybean plant was measured from the base to the growing point using a tape measure (cm). Biomass was measured at the R6 and R8 growth stages. Seed mass was determined at the R8 growth stage by cutting all above-ground biomass from two soybean rows of 1.5 m each, per plot. Soybean fresh mass was determined and a small subsample retained for dry matter determination. Pods were taken from three plants and the fresh mass and the dry mass weighed, before the rest of the biomass was taken back to the correct plots. Samples were dried in the oven overnight (80 °C) and weighed again. Samples were sent to FAS for nutrient analysis. At the same time, root samples were collected by digging 0.5 m x 2 rows of roots per plot. The roots were washed carefully with tap water and, weighed, dried overnight (80 °C) and reweighed to obtain dry weight. Roots sample was taken to FAS for nutrient analysis.

After soybean harvest, a Beater auger was used to take soil samples in the interrows in each plot. Twenty to thirty subsamples were collected per plot and combined into one bag per plot for soil nitrogen analysis. After sugarcane was replanted across the trial, a 4 m section of the two middle rows in each plot was pegged, and this area was used for the consecutive measurements. The date of sugarcane emergence was recorded. After stalk emergence, five plants were selected within the demarcated area in each plot and marked with red tape. Stalk height was measured on the five marked plants every week from the ground to the top visible dewlap (TVD), the uppermost visible collar between the leaf sheath and the leaf blade using

a wooden ruler. Leaves were counted from the lowest leaf up to the TVD leaf; every time the height was measured, the TVD leaf was numbered with permanent marker. Leaf chlorophyll content was also estimated on the five marked plants every week on the TVD leaf using a SPAD Logger.

Tillers were counted within the 2 rows x 4 m every week and the results were converted to tiller population per hectare. At the 14-leaf sugarcane growth stage, 30 of the third leaves (counting from the uppermost leaf more than halfway unfurled) were collected from each plot, and sent to FAS for nutrient analysis. Soil samples were collected after three months to determine the nutritional status of the soil after replanting sugarcane. Five locations were selected per plot, with one point on the centre and four points close to the corners. At each location, six subsamples were composited for each depth 0-20 cm and 20–40 cm. Soil samples were also collected for nematode enumeration. A spade was used to collect soil and roots from three places within each plot.

### **3.3.4 Crop yield**

The date of harvest maturity was recorded for the soybeans when all the leaves had dropped, all pods were brown and they shattered when squeezed by hand. The aerial biomass was cut down and removed completely from the plot and roots were left in the ground. The whole soybean harvesting process has been discussed above. Sugarcane was harvested when it was 12 months old at Mount Edgecombe and Pongola. At Bruynshill, sugarcane was harvested when it was 24 months old, the commercial standard in the area due to environmental conditions. Sugarcane was harvested without burning. Stalk heights and tiller counts were recorded directly before harvest. Cane knives were used to cut sugarcane stalks at ground level, and the dead leaves and green tops were removed from the stalks. After cutting the net plot (leaving one guard row standing at each side of the trial), sugarcane stalks were weighed using a vehicle-mounted grab and balance. A sample of 12 stalks from each plot was sent to the SASRI mill room for analysis of brix %, Pol %, Estimated Recoverable Crystal (ERC %), purity, sucrose content and dry matter.

### **3.3.5 Ratoon crop maintenance (Mount Edgecombe)**

The sugarcane crop which regrows from the cut stubble after harvest is referred to as the ratoon crop. At Bruynshill and Pongola, data was collected from the plant crop (the first crop harvested after planting seed cane) and at Mount Edgecombe data were collected from the plant crop and the first ratoon crop. After harvesting the plant crop, sugarcane trash (dead leaves) and green tops were spread over the plots. Plots were re-pegged and irrigation dripper lines re-laid on the field. All other measurements were similar to those collected in the plant crop. The fertilizer regime and crop maintenance were the same as described above for the plant crop.

### **3.3.6. Analysis of data**

The plant and soil nutrient data were subjected to analyses of variance (ANOVA) using Genstat<sup>®</sup> (Version 14) and mean separation was done using the least significant difference (LSD) and the Holm-Sidak test. Observed significant differences have been expressed in the text according to the level of probability. Standard errors of the mean were calculated.

## CHAPTER 4

### THE EFFECT OF SOYBEAN-SUGARCANE CROP ROTATION ON SUGARCANE GROWTH AND DEVELOPMENT ALONG THE COASTAL REGIONS OF KWAZULU-NATAL

#### 4.1 Abstract

Crop rotation is not commonly practised in the sugarcane industry in South Africa. It has, however, proven to be beneficial to other crops in South Africa. The objective of this study was to determine the impact of soybean-sugarcane crop rotation on selected physiological and phenological indicators of sugarcane performance and its subsequent effect on cane and estimated recoverable crystal (ERC) yields. A field trial was conducted at Mount Edgecombe, where soybean cultivar A5409RG and sugarcane cultivar NCo376 were planted under drip irrigation with different management practices. After the soybean crop, the following sugarcane crop was planted and fertilized with different levels of nitrogen (N) fertilizer (50% and 100% of the recommended N rate). The effects on sugarcane growth were recorded by taking into consideration date of emergence, plant height, tiller population, leaf N, plant performance index and chlorophyll content. Sugarcane yield and quality at harvest were also evaluated. Tiller population in all crop rotation treatments at Mount Edgecombe were significantly ( $P < 0.05$ ) higher than the monocrop treatment. There was a trend of increased leaf N in all of the cane-after-soya (crop rotation) crops compared to the cane-after-cane (monocrop) treatment, although this was not significant. A similar pattern was obtained with respect to the chlorophyll content and plant performance index. Sugarcane yields at Mount Edgecombe did not differ significantly between monocrop and crop rotation treatments. Crop rotation with soybean is beneficial for cane production, but its long term impact on soil quality and farm economy requires further investigation.

## 4.2 Introduction

Monoculture is the most commonly used production system worldwide in sugarcane (*Saccharum officinarum*) production. This production system leads to a decline in sugarcane yields and depletion of soil fertility (Shoko, *et al.*, 2009). The rainfed environments of the South African sugar industry are partitioned into three broad regions – coastal, hinterland and midlands characterized by different production conditions. However this study only concentrates on the coastal region which is characterized by areas with low altitude (< 200 m asl), relatively higher temperatures, and high topographic, soil, and rainfall variability. Sugarcane production in South Africa predominantly occurs along the east coast, extending from approximately 25°33'S to 30°93'S and between 29°92'E and 32°32'E, under a diverse range of conditions. Sugarcane in South Africa is grown in environments that are occasionally not typically conducive to a tropical crop. Nevertheless, the South African sugar industry is still a cost-competitive producer of approximately 2.2 million tons of sugar per annum from an estimated 430 000 ha under cultivation (Meyer, 2001). In South Africa, planting usually occurs in spring, summer and early autumn (preferred due to better soil moisture conditions). Germination, tillering, and stalk elongation rates are highly dependent on genotypic and environmental factors (Smit *et al.*, 2004). The crop is harvested when sucrose accumulation within the stalks reaches a peak, and the time to maturity also varies depending on genotype and growing conditions. In South Africa, sugarcane is harvested any time between 12 and 24 months of age, depending on temperatures (influenced by altitude). In the northern production area (where sugarcane is grown under irrigated conditions), harvesting generally occurs at 12 months of age, while along the coastal belt, sugarcane is generally harvested between 12 and 15 months of age (Smith, 1992).

Sugarcane requires a summer growing season which is warm to hot, with daily mean temperatures optimally between 22 °C and 32 °C, together with an abundance of sunshine (> 1200 hours p.a.) and moist conditions. This should be followed by a dry, but sunny and frost-free (only very light frosts tolerated) winter ripening and harvesting period during which relative humidity should be < 70%. Little growth takes

place at temperatures  $< 20\text{ }^{\circ}\text{C}$  and  $> 34\text{ }^{\circ}\text{C}$  and for sugarcane, soil temperatures are as important as air temperatures.

Production areas in KwaZulu-Natal are limited by the July minimum temperature isotherm of  $5\text{ }^{\circ}\text{C}$ . The crop grows well on a range of soils, but prefers well structured and aerated loams and sandy loam. Sugarcane yields less well on sandy soils due to the damaging effects of plant-parasitic nematodes, along with reduced nutrient and moisture retention capacity (SASRI, 2013), while on clayey soils root development may be hindered. The crop can withstand short spells of waterlogging.

Crop rotation is not commonly practised in the sugarcane industry in South Africa. It has, however, proven to be beneficial to other crops in South Africa and for sugarcane production in other countries (e.g. India and Pakistan). Monoculture can cause a build up of diseases (Pankhurst *et al.*, 1999), and this monoculture cycle can only be broken by practising crop rotation (Capriel *et al.*, 1992). Crop rotation with soybean (*Glycine max*) improved maize yields in South Africa by 30 to 50% (Nel, 2005), and has increased sugarcane yield in Australia by 20 to 30% (Garside *et al.*, 1999), with residual effects lasting for several ratoon crops (Garside & Bell, 2007).

Soybean can be used as a break crop, and as a green manure crop, since it can be returned to the soil as green mulch (Rhodes, 2006). Rotation with legumes provides both a source of fixed nitrogen and improvements in soil health (Garside *et al.*, 1998). Soybeans can be used as a cash crop (Bell, 2007) and can reduce fertilizer input costs due to the crop's ability to fix atmospheric nitrogen (Schroeder *et al.*, 2005). Soybean has been shown to reduce disease incidence (soil borne diseases and nematodes) (Charleston & Garside, 2000), improve moisture conservation under dryland cropping conditions, improve soil structure and soil nitrogen status (Poggio, 2006).

South Africa does not produce enough soybeans to supply current demand and more than a million tonnes are imported annually (AFMA, 2009). Soybean protein is used predominantly for animal feed and the oil is used for edible oil and for bio-fuel. Soybeans have not been grown in the South African sugarcane belt as a cash crop

and agronomic research is needed in order to characterise growth behaviour and cropping risks. The objective of the study was to quantify the impact of soybean-sugarcane crop rotation on cane growth and cane yield.

### 4.3 Materials and methods

#### 4.3.1 Site

The site selected for this study was Mount Edgecombe. This site was chosen to represent the coastal region of the sugar industry, with the aim of obtaining a clear indication of the performance of crop rotation in sugarcane along the coast. It was in close proximity to an automatic weather station. Experimental details have already been described in chapter 3.

### 4.4 Results and discussion

#### 4.4.1 Soil fertility

Soil results taken before planting indicate a low organic matter (%) and a high pH (Table 4.1). After soybean harvest organic matter was increased on the interrow and on the row. Again after soybean harvest pH was reduced. This is an indication that soybean can increase organic matter and reduce pH in the soil. Table 4.2 shows the analysis results of the soil samples collected after soybean harvest. There were no significant differences ( $P>0.05$ ) in any elements between the rows (where soybeans grew) and the inter-row soil where no soybeans had been planted. These indicate that the change in the soil can take time to be detected.

Table 4.1: Mount Edgecombe soil analysis results before soybean planting

	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	pH (H <sub>2</sub> O)	Na (ppm)	Clay (%)	OM (%)	NH <sub>3</sub> (%)
0-20 cm	23.2	140.6	613.3	212.2	5.3	40.8	25.0	1.6	0.7
20-40 cm	16.0	38.7	690.8	234.5	5.8	55.1	23.3	1.5	1.2

Table 4.2: Mount Edgecombe soil analysis results (row and interrow) directly after soybean harvest.

	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	pH (H <sub>2</sub> O)	Na (ppm)	Clay (%)	OM (%)	P (ppm)
Row	8.27	23.87	97.44	36.89	0.17	0.15	5.83	2.93	0.68
Interrow	8.52	25.43	94.29	32.53	0.18	0.16	5.49	2.56	0.78

#### 4.4.2 Performance of soybeans

All soybeans were treated equally at planting, and treatment differences were only imposed at soybean harvest. Soybeans emerged 7 days after planting in all plots and took approximately 57 days to flower. Pods were formed 72 days after planting. The average height and dry aerial biomass at the R5 growth stage of soybeans at Mount Edgecombe was 62.1 cm and 5.2 t/ha, respectively. According to the ARC Grain Crop Institute (2013), the grain yield at Mount Edgecombe was acceptable for a first time effort, at 2.61 t/ha (Table 4.5). The target soybean population was 400,000/ha and calibration problems with a borrowed planter mostly likely resulted in the low population counts (Table 4.5). The 7.8% moisture in the soybean grain was unusually low – commercial soybeans in South Africa are often harvested at 12-15% moisture -but this fell within the 12% upper limit of acceptable moisture content for mass storage.

Table 4.3: Soybeans yield for Mount Edgecombe (ME) at harvest.

Grain (t/ha)	Population (stalks/ha)	Height (cm)	Biomass (t/ha)	Grain moisture (%)
2.61	200 740	70.26	5.99	7.83

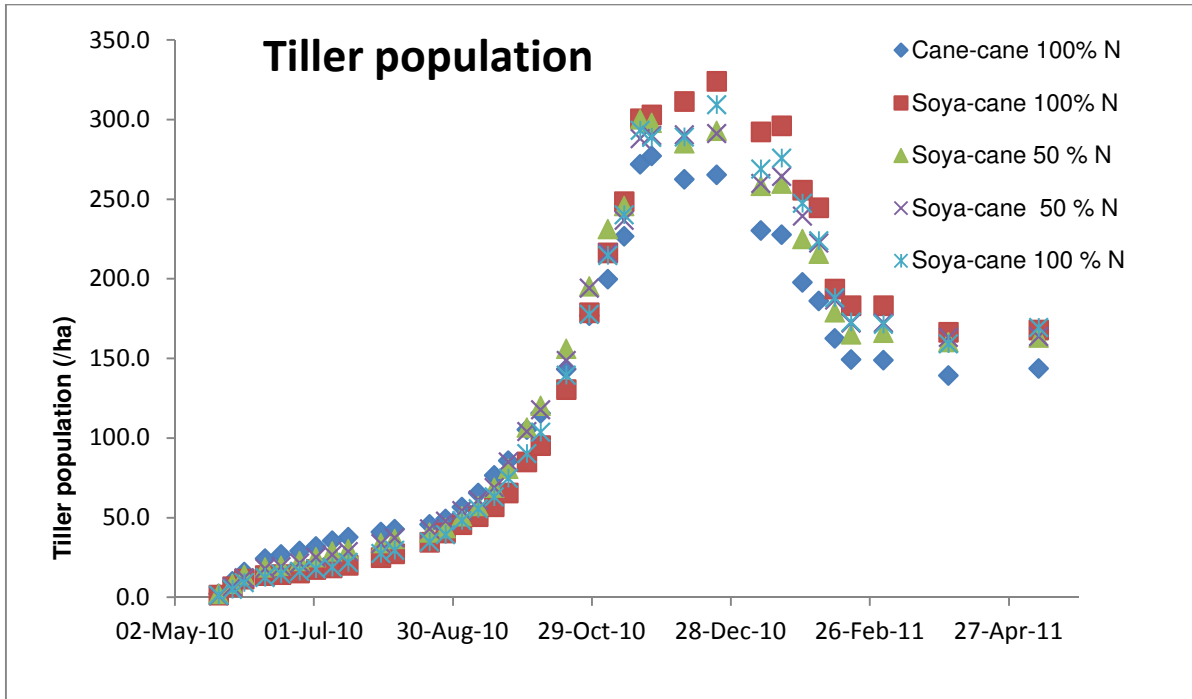
### 4.4.3 Sugarcane crop growth and development

#### 4.4.3.1 Tiller population

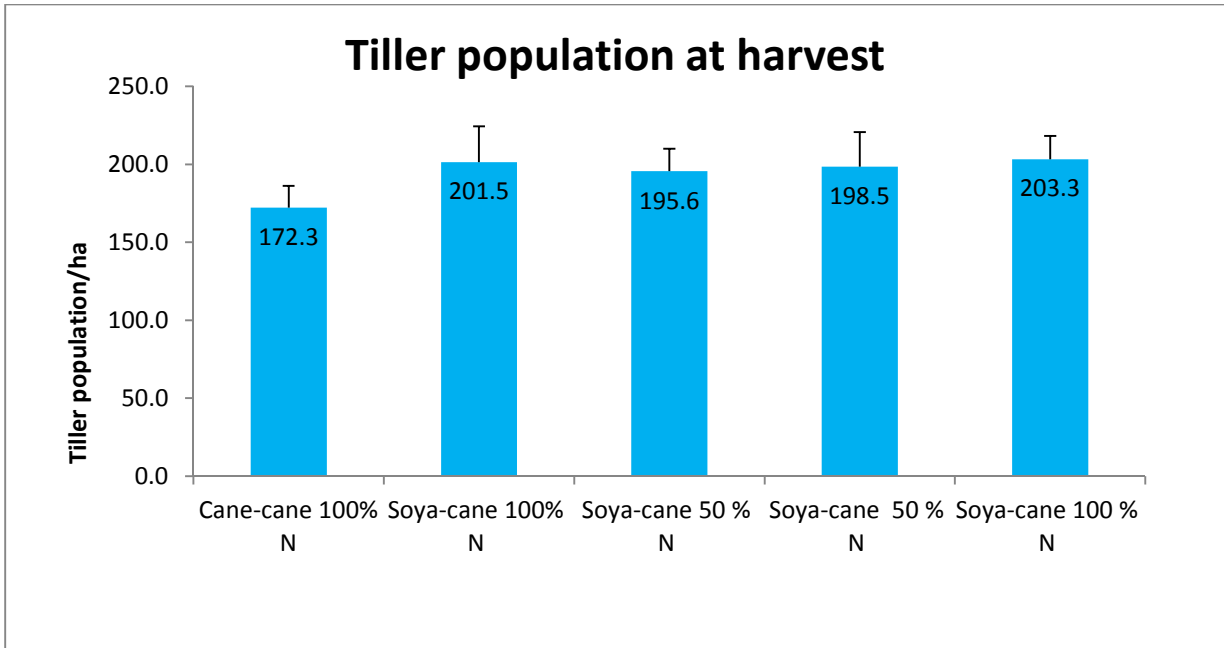
At Mount Edgecombe (Figure 4.1A), the time of emergence and time to reach peak population was similar for all treatments, although there were lower stalk numbers in the monocrop treatment at peak tillering. After peak tillering, all crop rotation treatments showed higher stalk populations than the monocrop treatment. There were no significant differences ( $P>0.5$ ) between the crop rotation treatments despite the different levels of N fertilizer applied at Mount Edgecombe. This indicated good tillering of sugarcane after soybeans, despite a reduction in the amount N applied.

Tillers give the farmers the final stalk. The more the tiller numbers the higher the yield (Zhou, 2004). Tiller population at harvest indicated the same trend where monocrop treatment had low number of stalks, however there was no significant difference ( $P>0.5$ ) between crop rotation and monocrop treatments (Figure 4.2). There was also no significant differences between the 50 and 100%N rotation treatments. This means that reducing N had no effects on final stalk population.

It is possible that the reduced tiller population in the monocrop treatment could have been a result of residual glyphosate after termination of the preceding cane crop, sprayed three weeks beforehand. The residual of glyphosate could have affected the germination of new sugarcane plant even though new sugarcane was planted between old lines. There is evidence from the literature that glyphosate can persist for up to 6 weeks in the soil (Roberts, 1998) and this might have affected the newly planted sugarcane.



**Figure 4.1:** Sugarcane tiller population at Mount Edgecombe. Tiller (stalk) population was measured over 4 m in each of the middle two cane rows of each plot. These counts were then calculated into tiller population/ha as shown in this graph above. Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soya-cane 100% N (soybean followed by sugarcane with 100% N); soya-cane 50% N (soybean followed by sugarcane with 50% N); soya-cane 50 % N (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soya-cane 100% N (soybean followed by sugarcane with 100% N).

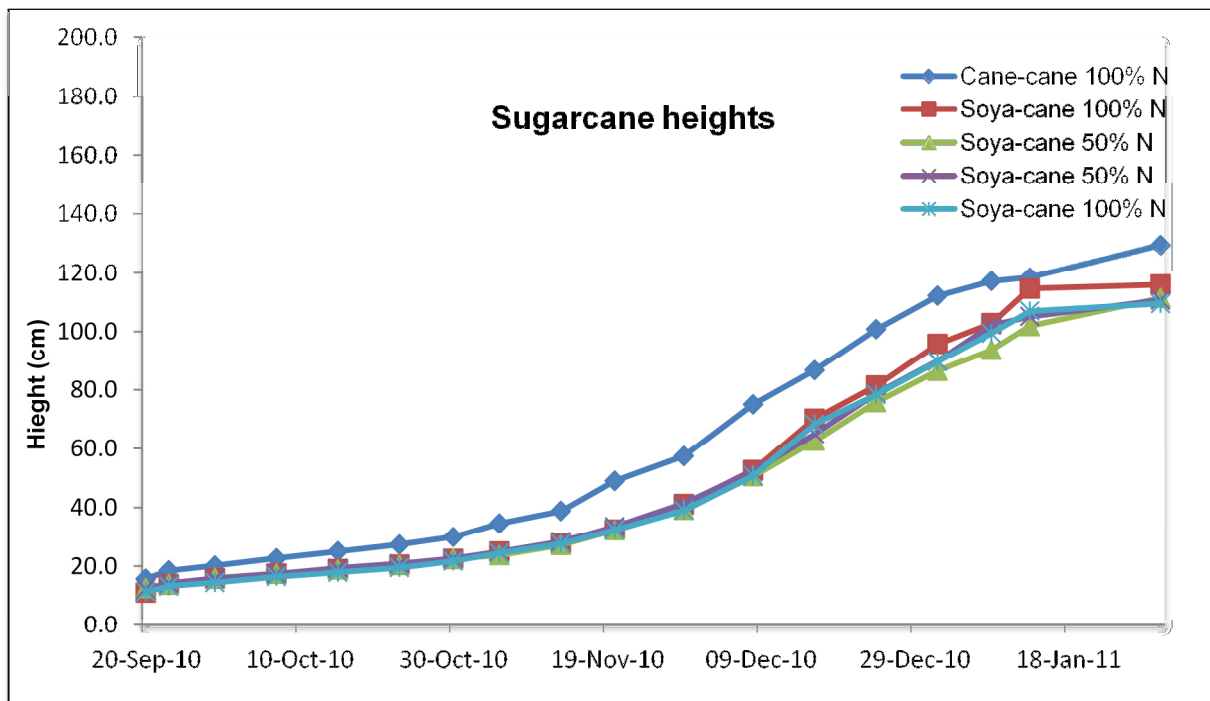


**Figure 4.2:** Sugarcane tiller population at harvest in Mount Edgecombe. Tiller (stalk) population was measured over 4 m in each of the middle two cane rows of each plot. These counts were then calculated into tiller population/ha as shown in this graph above. Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soya-cane 100% N (soybean followed by sugarcane with 100% N); soya-cane 50% N (soybean followed by sugarcane with 50% N); soya-cane 50% N (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soya-cane 100% N (soybean followed by sugarcane with 100% N).

#### 4.4.3.2 Sugarcane height

Sugarcane growth was slow from the time of emergence until October when stalk extension rate increased (Figure 4.3). Slow growth was possibly caused by low temperatures after planting and after the cool season the growth started to accelerate due to warmer temperatures. Early emergence of the monoculture treatment encouraged the growth rate of sugarcane to be faster and at all times measured, the monocrop treatment performed better than crop rotation treatments. There was, however, no significant difference ( $P > 0.5$ ) between the treatments.

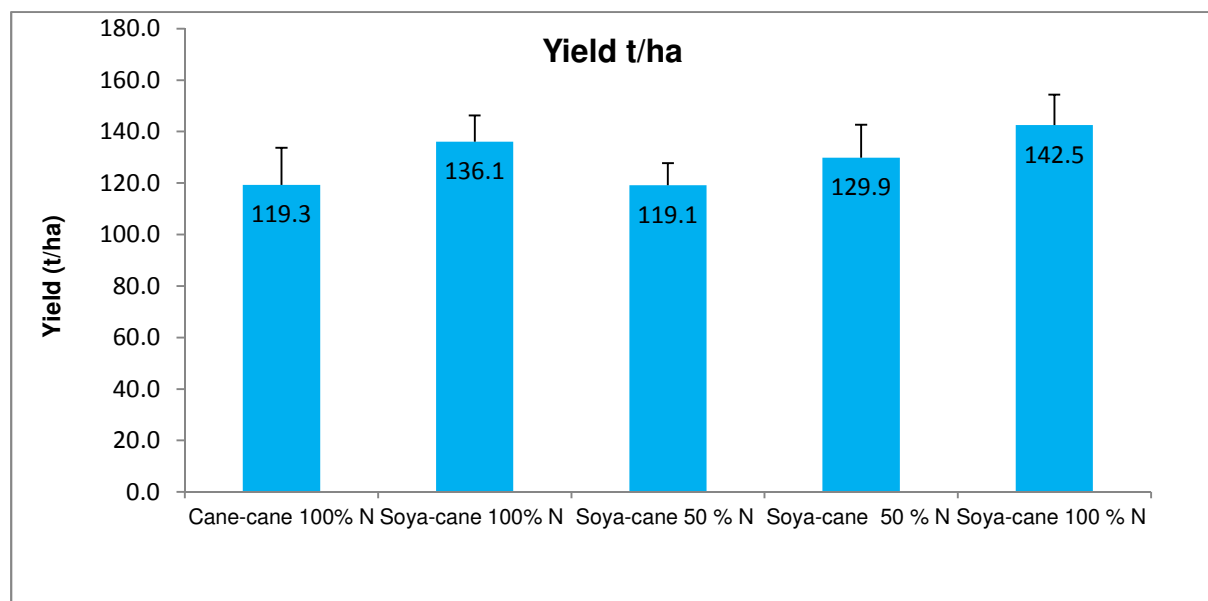
It was noted that sugarcane extension rate in the monoculture treatment was faster than that in the crop rotation treatments, while on the other hand the monocrop exhibited the lowest tiller population. It is possible that the reduced tiller population in the monocrop treatment could have been a result of residual glyphosate after termination of the preceding cane crop, sprayed three weeks beforehand. The residual of glyphosate could have affected the germination of new sugarcane plant even though new sugarcane was planted between old lines. There is evidence from the literature that glyphosate can persist for up to 6 weeks in the soil (Roberts, 1998) and this might have affected the newly planted sugarcane.



**Figure 4.3:** Sugarcane heights at Mount Edgecombe. Height (cm) was measured on 5 plants per plot in each of the middle two cane rows of each plot. Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soya-cane 100% N (soybean followed by sugarcane with 100% N); soya-cane 50% N (soybean followed by sugarcane with 50% N); soya-cane 50 % N (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soya-cane 100% N (soybean followed by sugarcane with 100% N).

#### 4.4.3.3 Sugarcane yield

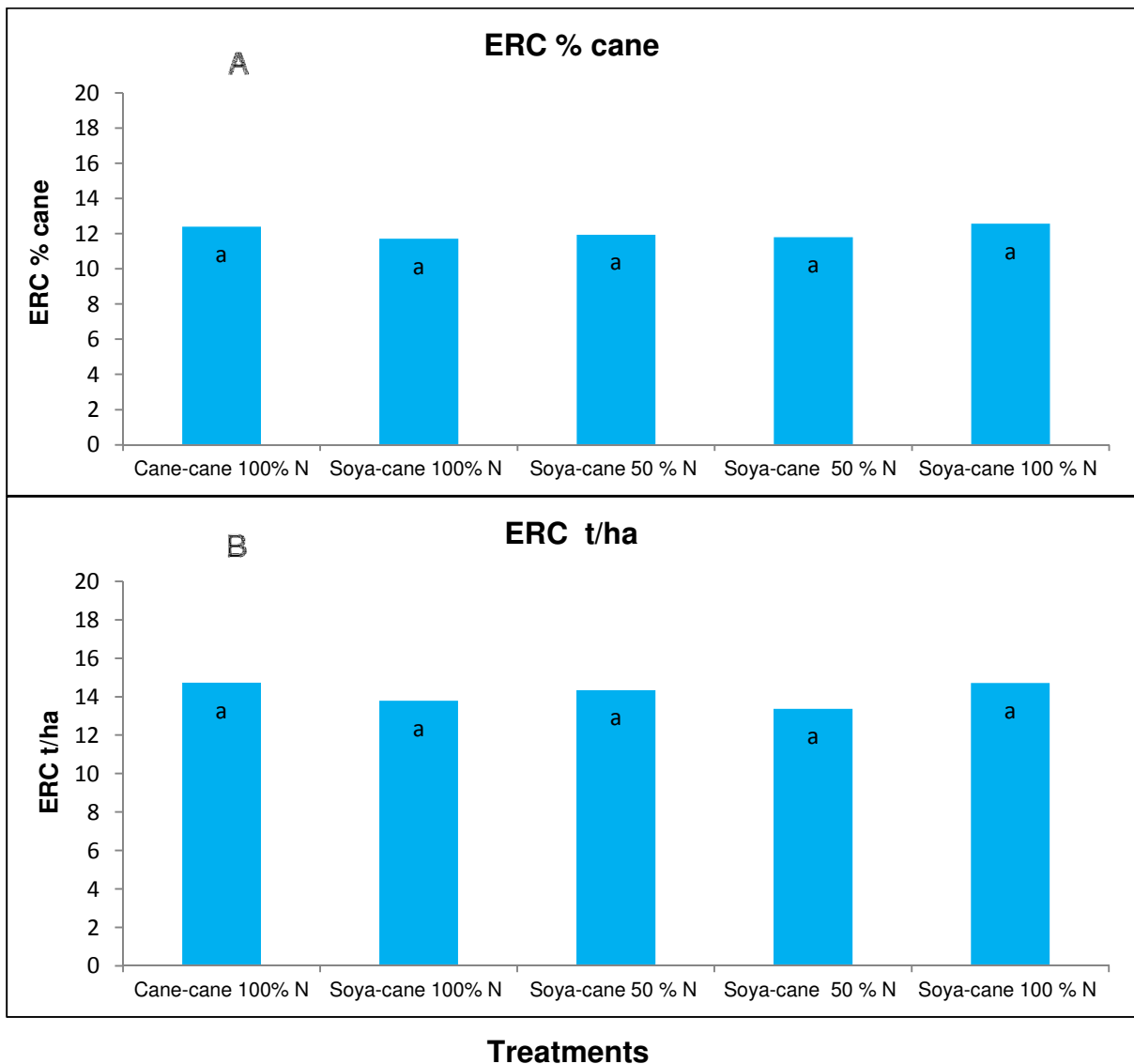
There were no significant differences ( $P>0.5$ ) between the yields from any of the treatments. This is counter-intuitive, considering the large number of studies, worldwide, indicating sugarcane yield benefits of between 10 and 58% following a legume crop rotation (Singh, 1974; Garside *et al.*, 1998; Garside *et al.*, 1999; Garside and Bell, 2001; Bokhtiar *et al.*, 2003; Nixon and Simmonds, 2004; Nixon, 2005; Garside *et al.*, 2006; Garside and Bell, 2007; Janboonme *et al.*, 2007; Umrit *et al.*, 2009; Ambrosano *et al.*, 2010; Garside and Bell, 2011). There were yield reductions, but these were not statistically significant. In other words, there were indications or tendencies for yield reductions associated with reduced N. This result indicates, however, that N reduction by up to 50% following crop rotation with soybeans has not reduced sugarcane yields, suggesting that growers could safely reduce N application in the plant crop following soybeans.



**Figure 4.4** Sugarcane yield (t/ha) in the plant crop at Mount Edgecombe. Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soya-cane 100% N (soybean followed by sugarcane with 100% N); soya-cane 50% N (soybean followed by sugarcane with 50% N); soya-cane 50% N (soybean with fodder (biomass) removed followed by

sugarcane with 50% N); soya-cane 100% N (soybean followed by sugarcane with 100% N).

The data shown in Figure 4.5 illustrate that there was no significant difference ( $P>0.5$ ) between the treatments in terms of ERC% (cane quality) or ERC t/ha (sucrose quantity). This confirms the same trends as seen in the cane yield data shown above. Sugarcane yield also had the same trend where there were no yield differences between the treatments.

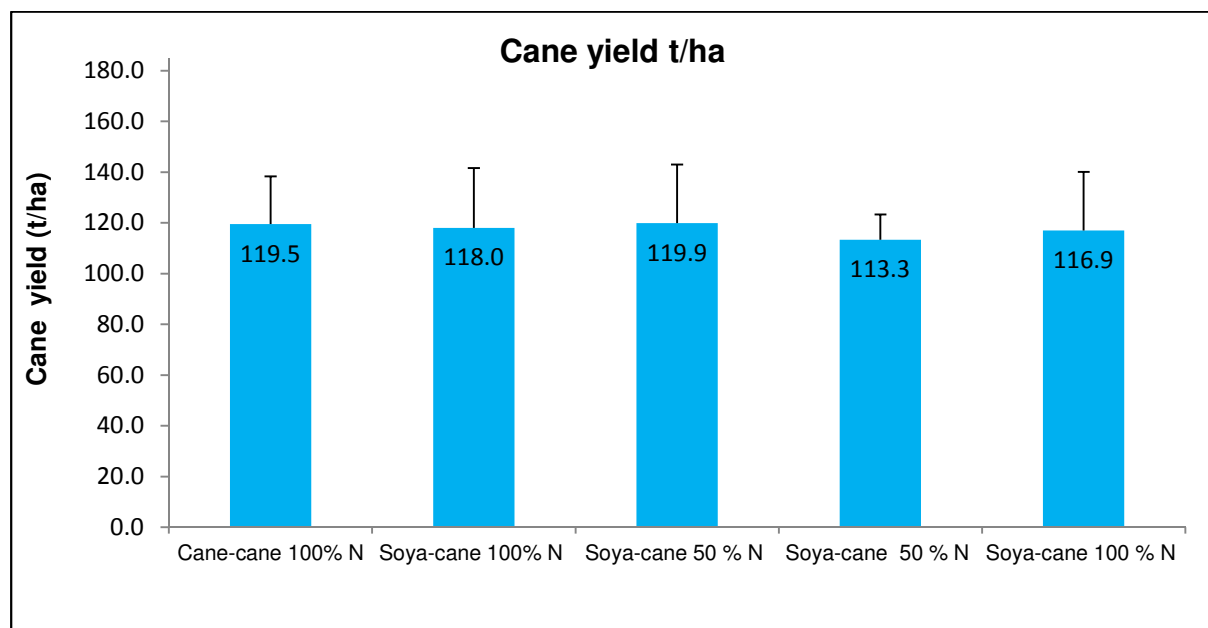


**Figure 4.5:** Estimated recoverable crystal ERC% cane (A) and tons ERC /ha (b) for the plant crop at the Mount Edgecombe trial.

#### 4.4.3.4 Ratoon 1 (Sugarcane yield)

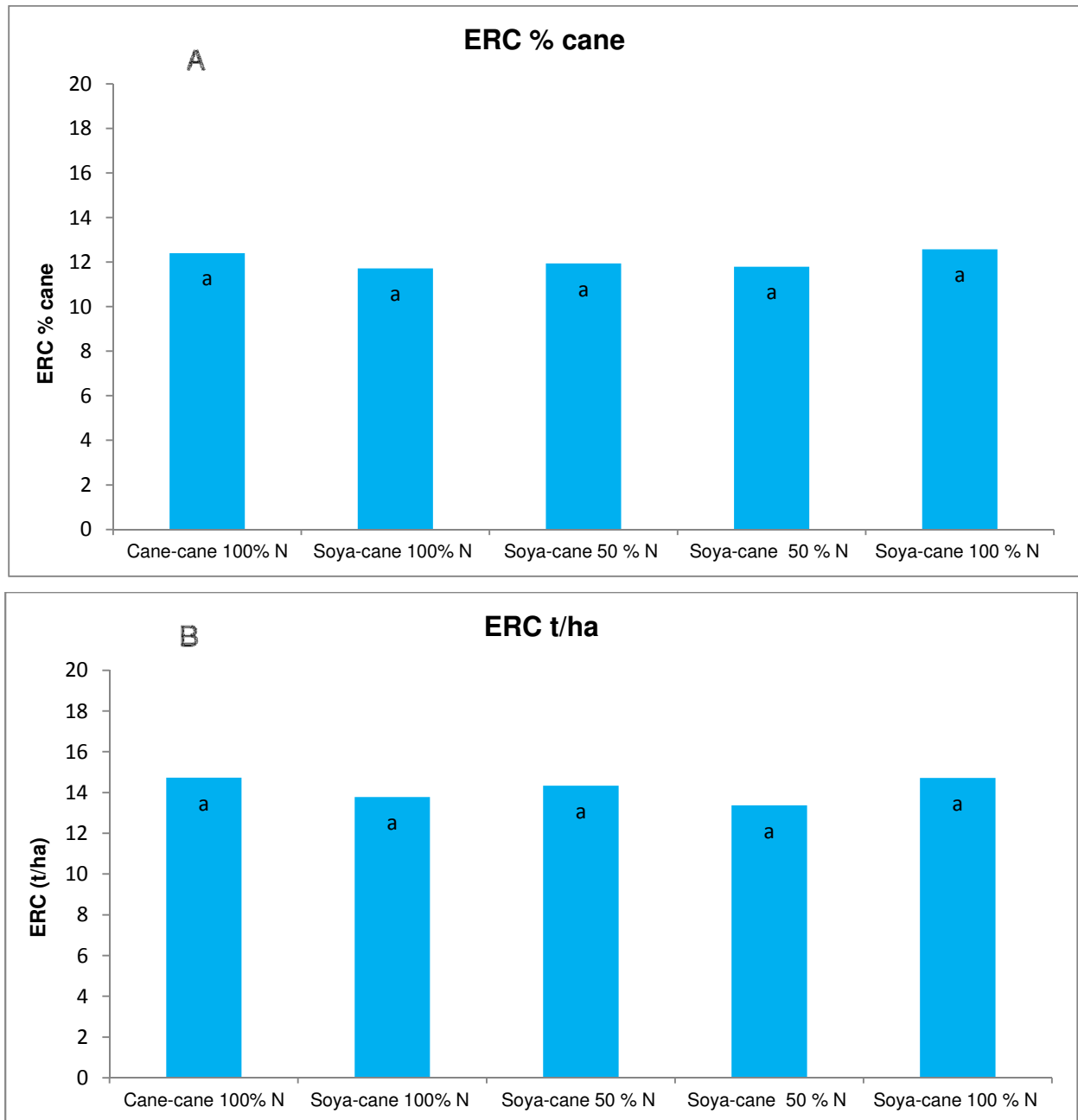
The first ratoon sugarcane crop at Mt Edgecombe had similar yield and quality results to the plant crop, and showed the same trends. Again, there were no significant differences ( $P>0.5$ ) between the treatments (Figure 4.6), which indicates that rotation of sugarcane with soybeans did not impact on sugarcane yield. In addition, different N rates after soybeans did not affect sugarcane yields, again suggesting that N reduction into the first ratoon crop following soybeans is a possibility for growers. The average yield was 117.5 t/ha which is slightly higher than the 100 t/ha predicted by SASRI's sugarcane crop forecasting model, Canesim.

Cane quality (ERC% and tons ERC/ha) exhibited no significant differences between treatments.



**Figure 4.6:** Sugarcane yield in the first ratoon crop at Mount Edgecombe. Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soya-cane 100% N (soybean followed by sugarcane with 100% N); soya-cane 50% N (soybean followed by sugarcane with 50% N); soya-cane 50% N (soybean with fodder (biomass) removed followed

by sugarcane with 50% N); soya-cane 100% N (soybean followed by sugarcane with 100% N).

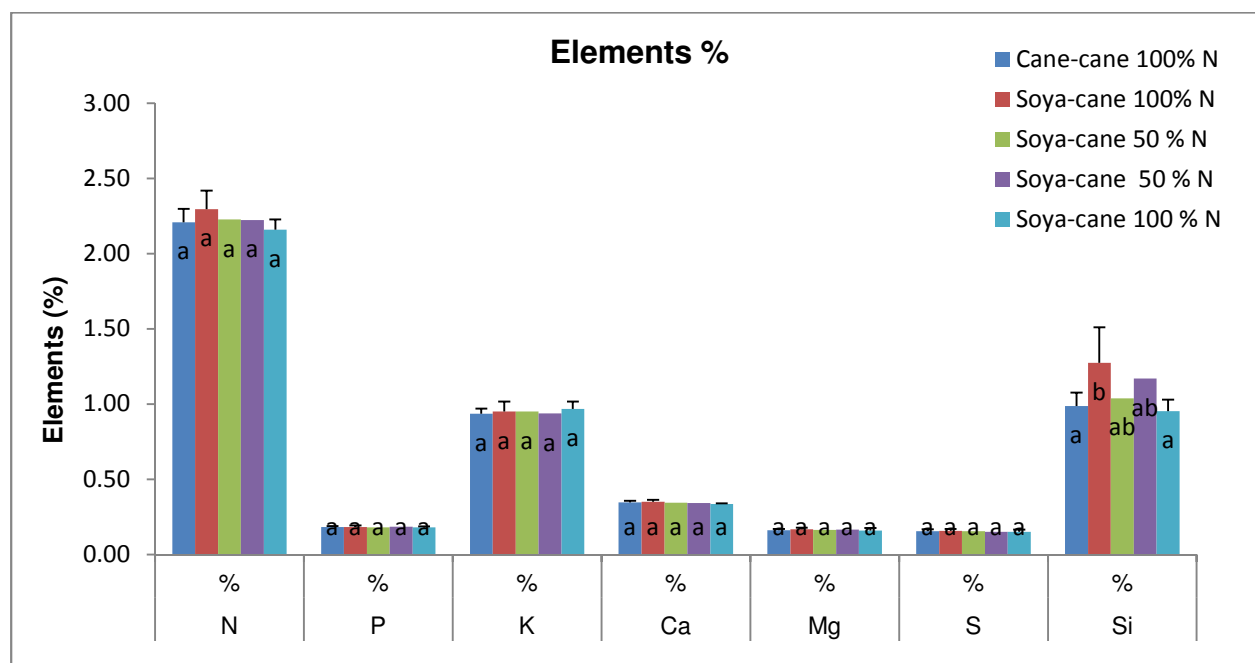


**Treatments**

**Figure 4.7:** Estimated recoverable crystal ERC% cane (A) and tons ERC /ha (B) for the plant crop at the Mount Edgecombe trial.

#### 4.4.4 Plant mineral nutrient content, chlorophyll and performance indices

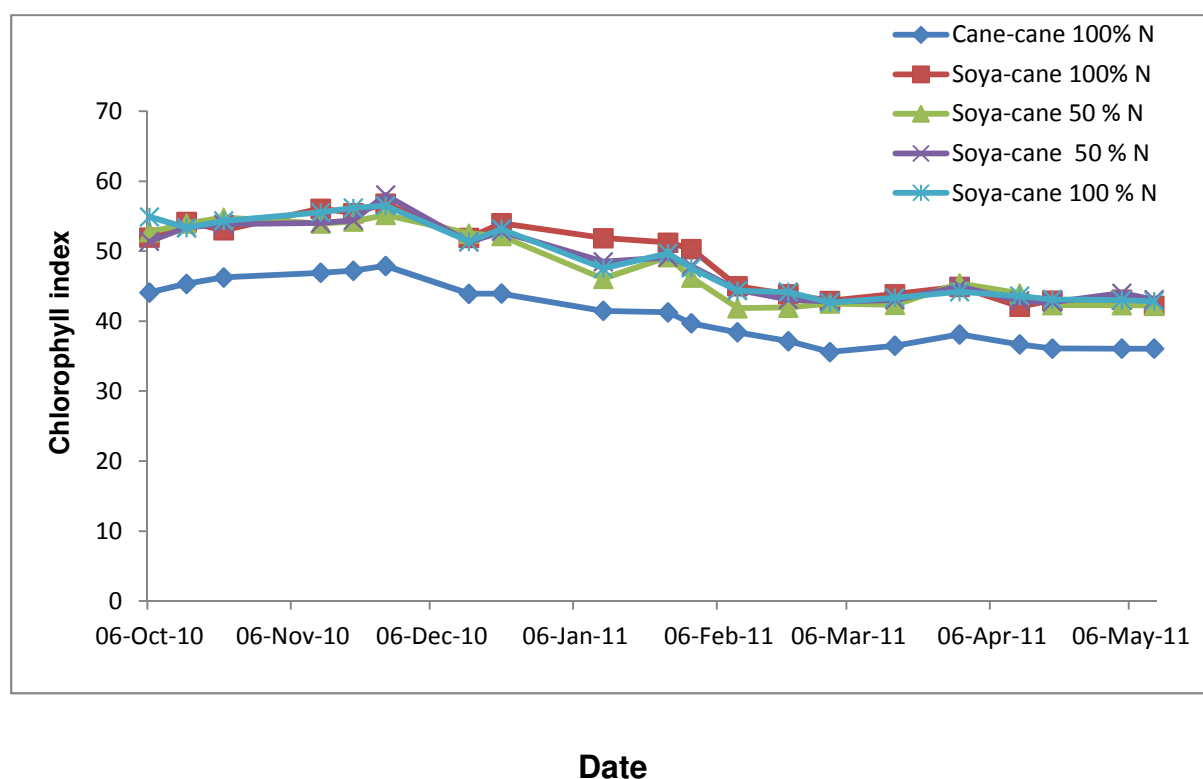
Leaf N in all four cane-after-soya treatments showed no significant differences compared to the cane-after-cane ‘monocrop’ treatment at this trial (Figure 4.7). This indicates that N from soybeans had possibly become available to the sugarcane at the 50% N fertilizer level, or that the plants were supplementing their nitrogen from residual N in the soil. No significant differences existed between the treatments for any of the other leaf nutrients either.



**Figure 4.8:** Sugarcane leaf analysis at 14 leaf growth stage in Mount Edgecombe.

Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soya-cane 100% N (soybean followed by sugarcane with 100% N); soya-cane 50% N (soybean followed by sugarcane with 50% N); soya-cane 50% N (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soya-cane 100% N (soybean followed by sugarcane with 100% N).

The chlorophyll index was slightly higher in all crop rotation treatments compared to the monocrop control (Figure 4.9), but this difference was not significant. Interestingly, this difference was also visually evident (Figure 4.10) where the sugarcane leaves in plots planted after soybeans had greener leaves than those plots planted after sugarcane. There was no significant difference between crop rotation treatments; same trend was seen on 50 and 100N treatments. This result shows that the reduction of N has less effect on chlorophyll content of the sugarcane plant.



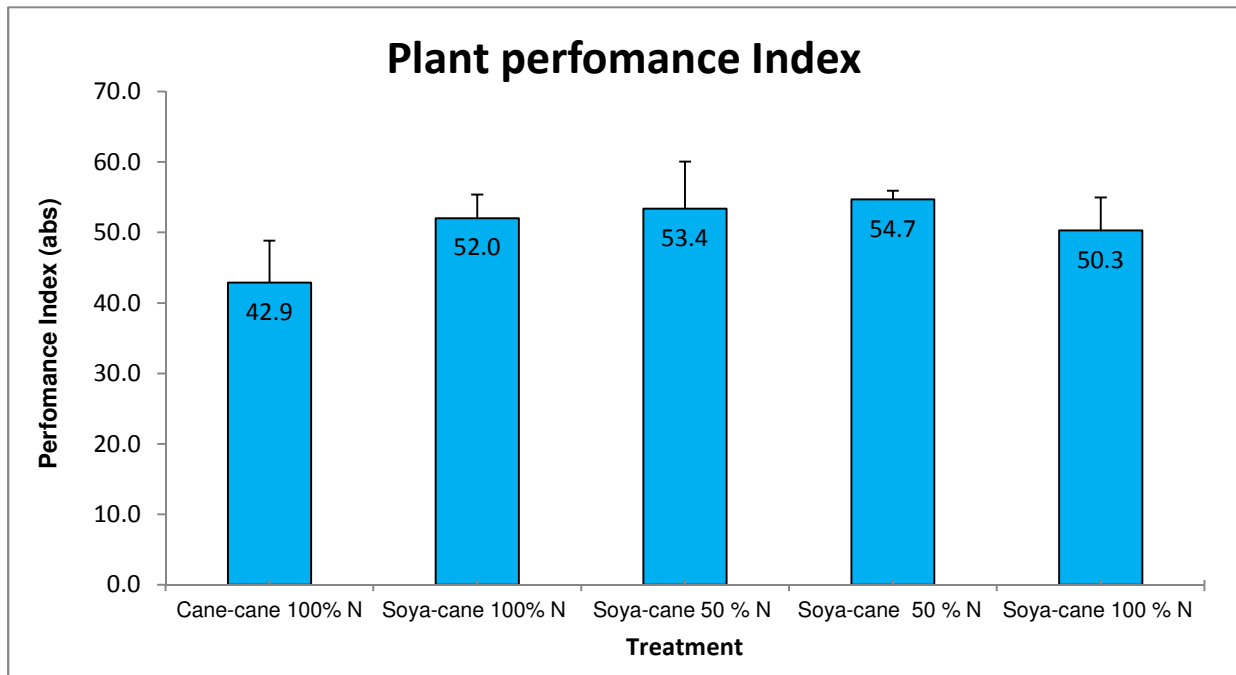
**Figure 4.9:** Chlorophyll Index at mount Edgecombe using a SPAD Logger. Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soya-cane 100% N (soybean followed by sugarcane with 100% N); soya-cane 50% N (soybean followed by sugarcane with 50% N); soya-cane 50 % N (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soya-cane 100% N (soybean followed by sugarcane with 100% N).



**Figure 4.10:** Crop rotation (left) and Monocrop (right) treatments at harvest.

Chlorophyll fluorescence in Mount Edgecombe (plant performance index) was measured with a Handy PEA chlorophyll fluorimeter when the sugarcane plant had 14 leaves. The chlorophyll fluorescence was measured at night on the TVD leaf. The sensor unit consists of an array of 3 ultra-bright red LED's optically filtered to a peak wavelength of 650 nm, which is readily absorbed by the chloroplasts of the leaf, at a maximum intensity of  $>3000 \mu\text{mol m}^{-2} \text{s}^{-1}$  at the sample surface. PEA chlorophyll fluorimeter measures several different data presentation techniques combined in order to effectively demonstrate subtle differences in the fluorescence signature of samples which could be indicative of stress factors affecting the photosynthetic efficiency of the plant. According to the results obtained in the Mount Edgecombe trial (Figure 4.11), the plant performance index was slightly higher in the four cane-after-soya crop rotation treatments than in the monocropping cane-after-cane

treatment, but this difference was not significant ( $P>0.5$ ). This gives some indication that sugarcane planted after soybeans had the ability to perform better than sugarcane planted after sugarcane. The addition of different rates of N fertilizer after soybeans had no effect on plant performance index amongst the crop rotation treatments.

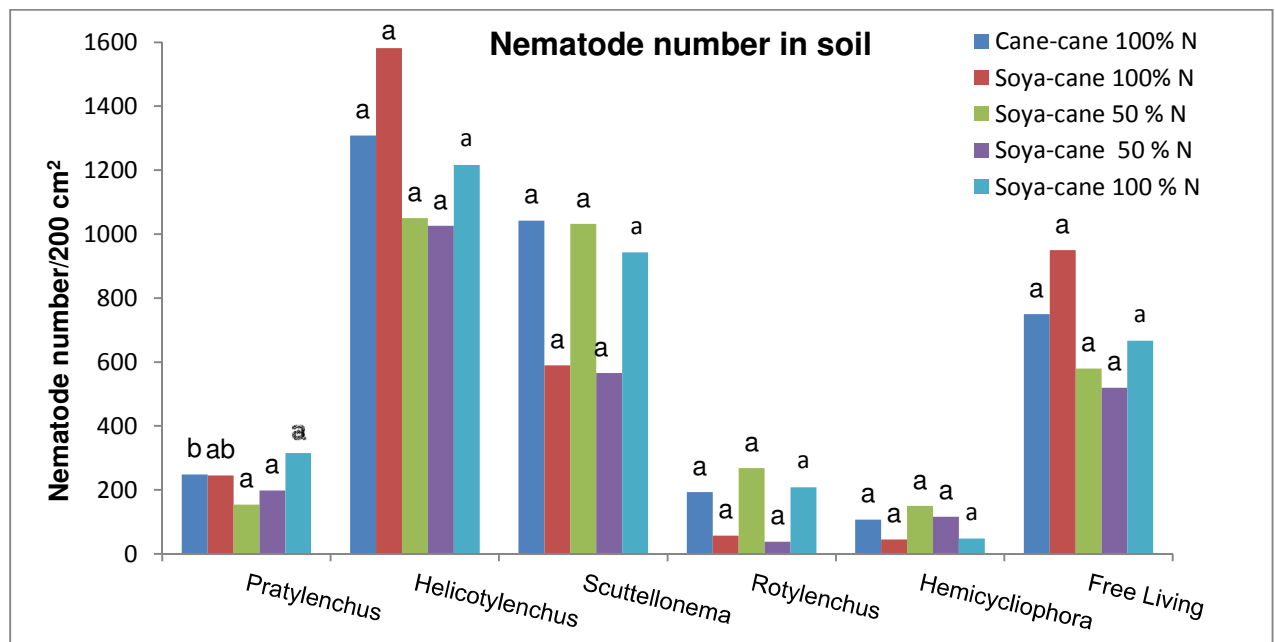


**Figure 4.11:** Plant Performance Index (using Leaf Area Meter). Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soy-cane 100% N (soybean followed by sugarcane with 100% N); soy-cane 50% N (soybean followed by sugarcane with 50% N); soy-cane 50 % N (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soy-cane 100% N (soybean followed by sugarcane with 100% N).

#### 4.4.5 Nematode counts in soil and roots

Results from nematode counts performed in soil at harvest of soybeans and sugarcane are shown in Figure 4.12. A large diversity of plant parasitic nematodes was found associated with cane at all sites. The genera *Pratylenchus*, *Helicotylenchus* and *Scutellonemawere* were found. Other genera such as *Rotylenchus*, *Hemicyclophora*, *Rotylenchulus* and *Paratrichodorus* were found at

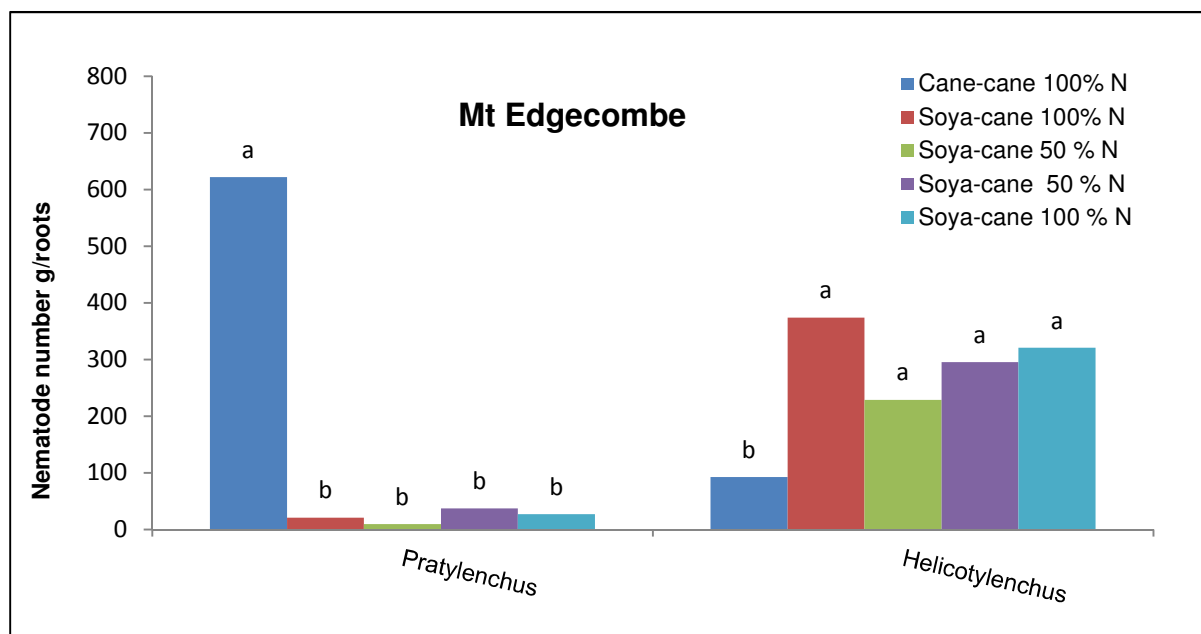
Mount Edgecombe. Soybeans tended to increase the numbers of *Helicotylenchus* compared to the cane control with the 100N treatment. However, these increases were not significant at the 5 % level. Nematode communities dominated by *Helicotylenchus* are less damaging to sugarcane than communities dominated by other plant parasitic nematodes (Spaull and Cadet, 2003). Free-living (non plant-parasitic) nematode numbers also tended to increase in the 100N soybean plots, although these results were not significant or consistent.



**Figure 4.12:** Nematode populations in the soil at Mount Edgecombe. Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soy-cane 50% N (soybean followed by sugarcane with 50% N); soy-cane 50 % N (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soy-cane 100% N (soybean followed by sugarcane with 100% N).

Results from nematode counts performed on roots at harvest are shown in Figure 4.13., A significantly lower ( $P < 0.05$ ) number of *Pratylenchus* was observed in the soya plots when compared to the cane control. No significant differences in *Pratylenchus* numbers were observed between any of the rotation treatments.

A significantly higher number of *Helicotylenchus* ( $P < 0.05$ ) was observed in the soybean plots (Figure 4.13). Sparkes and Charlestone (2002) also showed that cane following soybean fallows had an impact on plant parasitic nematodes compared to the monoculture of cane-cane. In addition to the reduction in parasitic nematodes after soybean fallows there was an increase ( $P < 0.5$ ) in free-living nematodes which indicates increased biological activity in the soil.



**Figure 4.13:** Nematode population in roots at Mount Edgecombe. Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soy-cane 50% N (soybean followed by sugarcane with 50% N); soy-cane 50% N (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soy-cane 100% N (soybean followed by sugarcane with 100% N).

#### 4.5 Conclusion

Sugarcane leaf samples collected from the plant crop, chlorophyll and plant performance index hint that N from the soybeans might have become available to the following sugarcane crop, though these trends were not significant. At the plant

crop harvest, however, there were no significant yield or ERC differences between the different treatments; sugarcane grown after soybeans did not produce higher yields than that grown after cane, nor were the yields significantly suppressed after growing soybeans. Crop rotation treatments on the first ratoon did not show any changes in terms of yield and quality.

Nematode counts showed that soybeans increased the numbers of the mitigating spiral nematode, *Helicotylenchus*, as well as increasing free-living (non plant-parasitic) nematode numbers. The plant-parasitic lesion nematode *Pratylenchus* was decreased significantly by the soybeans, in comparison to the cane plots. All of these factors indicate that crop rotation with soybeans has no deleterious effect on the succeeding sugarcane crop and might actually be beneficial to the next sugarcane crop, even if the increase in yields is not immediately visible or measurable. At plant crop harvest, cane-soya (soybean treated as green manure) had the highest yields compared to all other treatments including cane-soya (soybean grown to maturity). Even though yields didn't increase after soybeans, the non-significant differences between yields indicate that N can be reduced following soybeans and the reduction of application of fertilizer allows a farmer to save up to 50% of his/her N application without yield loss.

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## CHAPTER 5

### THE EFFECT OF A SOYBEAN-SUGARCANE CROP ROTATION ON SUGARCANE GROWTH AND DEVELOPMENT IN THE MIDLANDS REGION OF KWAZULU-NATAL

#### 5.1 Abstract

Crop rotation is not commonly practised in the sugarcane industry in South Africa. It has, however, proven to be beneficial to other crops in South Africa. The objective of this study was to determine the impact of soybean-sugarcane crop rotation on selected physiological and phenological indicators of cane performance and its subsequent effect on cane and estimated recoverable crystal (ERC) yields. A field trial was conducted at Bruynshill in the KwaZulu-Natal Midlands, where soybean cultivar A5409RG and sugarcane cultivar NCo376 were planted under drip irrigation with different management practices. After the soybean crop, the following sugarcane crop was planted and fertilized with different levels of nitrogen (N) fertilizer (50% and 100% of the recommended N rate). The effects on sugarcane growth were recorded by taking into consideration date of emergence, plant height, tiller population, leaf N and chlorophyll content. Sugarcane yield and quality at harvest were also evaluated. Tiller population in all crop rotation treatments were significantly ( $P < 0.05$ ) higher than the monocrop treatment. There was a trend of increased amount of leaf N in all of the cane-after-soya (crop rotation) crops compared to the cane-after-cane (monocrop) treatment, although this was not significant. Sugarcane yields were not significantly different between monocrop and crop rotation treatments. Crop rotation with soybean is beneficial for cane production, but its long term impact on soil quality and farm economy require further investigations.

## **5.2 Introduction**

The rainfed environments of the South African sugar industry are partitioned into three broad regions characterized by different production conditions. This study focuses on the KwaZulu-Natal Midlands region which is characterized by areas with high altitude (> 600 m asl), relatively lower temperatures, flat or undulating topography, generally more productive soils and lower rainfall variability. In the Midlands, sugarcane planting usually occurs in spring or early summer (preferred due to greater soil moisture and higher temperatures), and harvest age generally ranges from 15-24 months, unless frost damage necessitates an earlier harvest.

As in other areas of the South African sugar industry, years of monocropping has led to a reduction in soil health and cane yield. Growers are encouraged to break the monoculture with a crop rotation. Soybeans have been shown other industries (e.g. the Australian sugar industry (Garside *et al.*, 1998) to improve cane yields and relieve some of the effects of sugarcane monocropping.

The objective of the study was to quantify the impact of soybean-sugarcane crop rotation on cane growth and cane yield in the KwaZulu-Natal Midlands.

## **5.3 Materials and Methods**

The site selected for this study was at the South African Sugarcane Research Institute (SASRI)'s Bruynshill research station. This farm is near the small town of Harburg in the KwaZulu-Natal Midlands and is situated within close proximity to an automatic weather station. This site was chosen to represent the Midlands environmental conditions within the sugar industry, in order to obtain a clear indication of the performance of crop rotation in sugarcane across contrasting conditions. Experimental details have been outlined in Chapter 3.

## 5.4 Results and discussion

### 5.4.1 Soil fertility

There was a slight increase of organic matter after soybean harvest in soil. Soil pH was reduced after soybean harvest (Table 5.1). This shows that soybean can reduce pH in the soil. Table 5.2 shows the analysis results of the soil samples collected after soybean harvest. There were no significant differences ( $P>0.05$ ) in any elements between the rows (where soybeans grew) and the inter-row soil where no soybeans had been planted. These results indicate that the impact of soybean from the soil can be detected after a long time. The results also indicate that soybean add less N to the soil for the incoming crop.

Table 5.1: Bruynhill soil analysis results before soybean planting

	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	pH (H <sub>2</sub> O)	Na (ppm)	Clay (%)	OM (%)	NH <sub>3</sub> (%)
0-20 cm	37.4	128.6	193.0	70.7	4.9	18.8	32.0	3.5	0.2
20-40cm	37.3	138.0	252.9	86.3	4.9	19.0	34.1	3.6	0.2

Table 5.2: Bruynshill soil results (row and interrow) at soybean harvest.

	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	pH (H <sub>2</sub> O)	Na (ppm)	Clay (%)	OM (%)
(BH) Row	11.93	39.04	99.56	24.79	0.14	0.05	4.38	3.66
Interrow	10.73	44.43	101.4	24.59	0.14	0.05	4.98	3.75

## 5.4.2 Performance of soybeans

All soybeans were treated equally at planting, and treatment differences were only imposed at soybean harvest. Soybeans emerged 7 days after planting and took approximately 57 days to flower. Pods were formed 72 days after planting. The average height and dry aerial biomass at the R5 growth stage of soybeans at Bruynshill was 69.5 cm and 6.9 t/ha. Due to problems with the irrigation system at Bruynshill, the soybean crop was largely rain fed and therefore slightly water stressed. This could explain the lower grain yields (1.14 t/ha, Table 5.5). The 8.3% moisture in the soybean grain was unusually low – commercial soybeans in South Africa are often harvested at 12-15% moisture -but this fell within the 12% upper limit of acceptable moisture content for mass storage.

Table 5.3: Soybeans yield for Bruynshill at harvest.

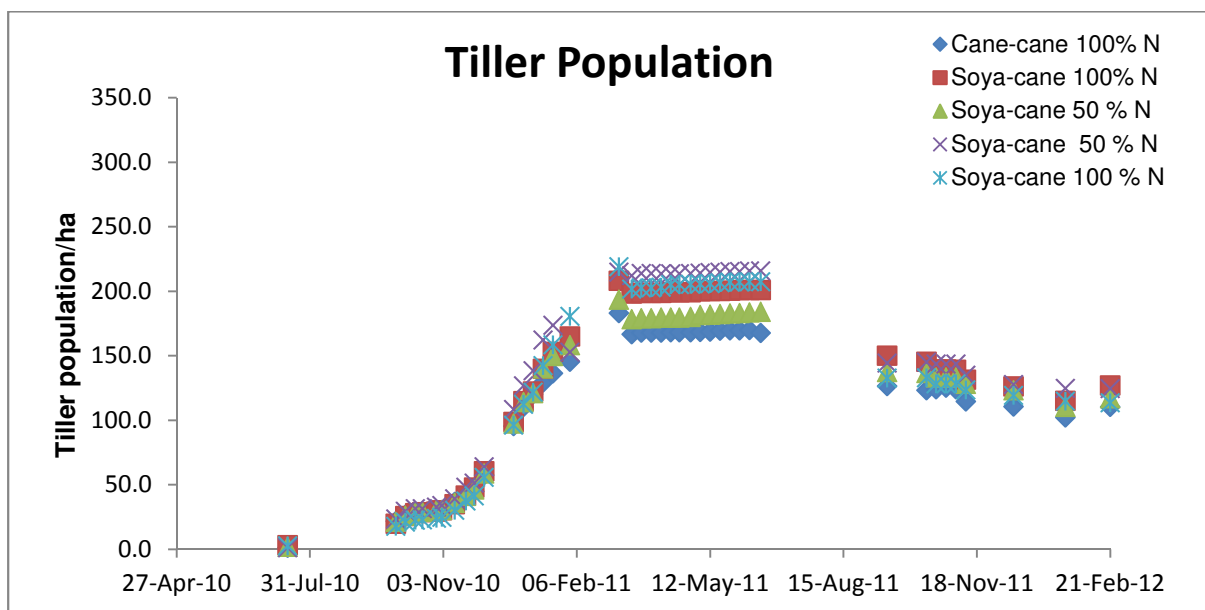
Grain (t/ha)	Population (stalks/ha)	Height (cm)	Biomass (t/ha)	Grain moisture (%)
1.14	346 419	70.27	6.03	8.36

## 5.4.3. Sugarcane crop growth and development

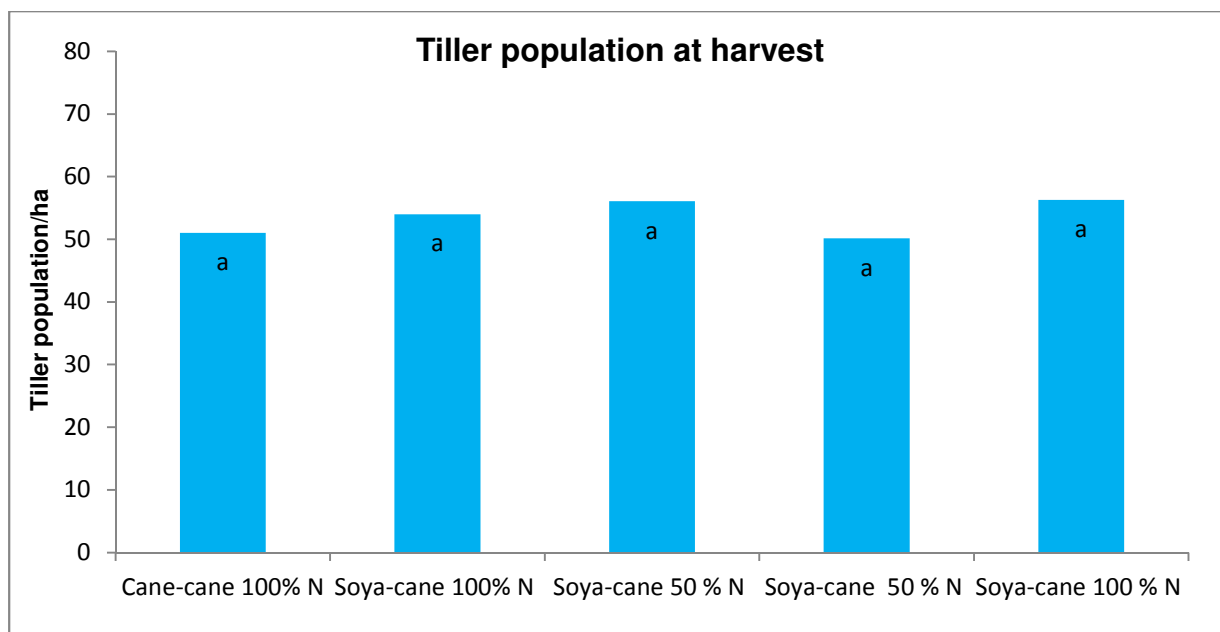
### 5.4.3.1 Tiller population

At Bruynshill (Figure 5.1), emergence of sugarcane started off slowly due to an autumn planting date; environmental factors were not conducive to emergence, especially at this cool Midlands site. Low temperatures can delay sugarcane germination. Tiller population was uniform from the time of emergence until January 2011, when the populations started to differ between treatments. The peak was achieved in approximately February 2011. Tiller population during winter 2011 was constant due to low temperatures and light intensity. Though not significant, treatment 1 – the cane-on-cane monocropping treatment - had the lowest tiller

population from February through to harvest compared to the other rotation treatments, suggesting that sugarcane tillering after soybeans was slightly increased. There were no significant differences ( $P>0.5$ ) at the time of sugarcane harvest (figure 5.2). The cane planted after soybean which was grown to grain harvest had the highest tiller population compared to monocrop and treatment 5-cane planted after soybean crop treated as green manure. This is in contrast with the results obtained by Shoko *et al.*, 2007 where grain soybean treatment of 80 and 120 kg nitrogen produced less tillers than monoculture cane in Zimbabwe.



**Figure 5.1:** Tiller population at Bruynshill. Tiller (stalk) population was measured over 4 m in each of the middle two cane rows of each plot. These counts were then calculated into tiller population/ha as shown on the graph. Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soya-cane 100% N (soybean followed by sugarcane with 100% N); soya-cane 50% N (soybean followed by sugarcane with 50% N); soya-cane 50% N (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soya-cane 100% N (soybean followed by sugarcane with 100% N).

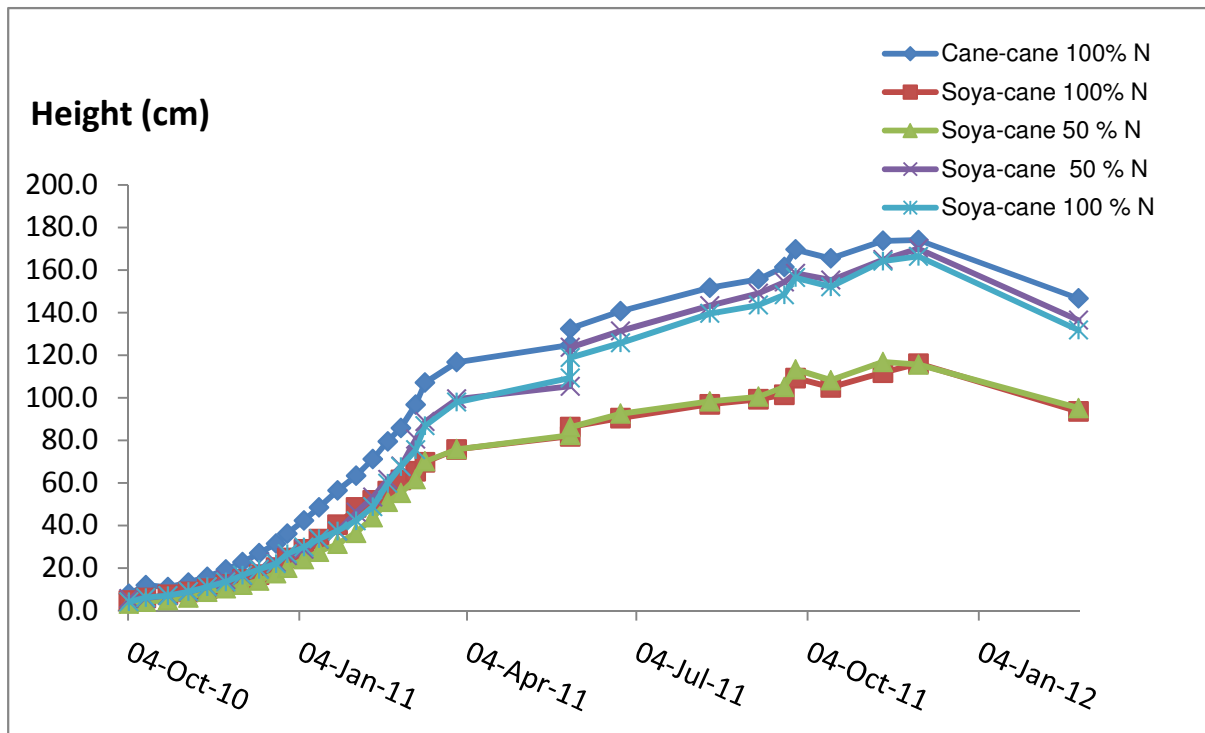


**Figure 5.2:** Tiller population at harvest in Bruynshill. Tiller (stalk) population was measured over 4 m in each of the middle two cane rows of each plot. These counts were then calculated into tiller population/ha. Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soy-cane 100% N (soybean followed by sugarcane with 100% N); soy-cane 50% N (soybean followed by sugarcane with 50% N); soy-cane 50 % N (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soy-cane 100% N (soybean followed by sugarcane with 100% N).

#### 5.4.3.2 Sugarcane height

The stalk extension rate also started slowly during the cool season and then the growth rate began to increase during the warmer season. All treatments showed a similar pattern from the time of emergence until approximately April/May 2011, when diversity between treatments began to become evident (Figure 5.2). By this stage, the crop rotation treatments with cane-soya 50% and 100% N (soybean grown to harvest as grain) were the shortest compared to other treatments. Cane-soya (soybean treated as fodder and green manure) had a higher stalk height compared

to cane-soya (soybean grown to grain harvest), this indicate that soybean grown to grain harvest suppressed growth of sugarcane (height). Despite visual observations, there were no significant height differences ( $P>0.5$ ) between the treatments at harvest.

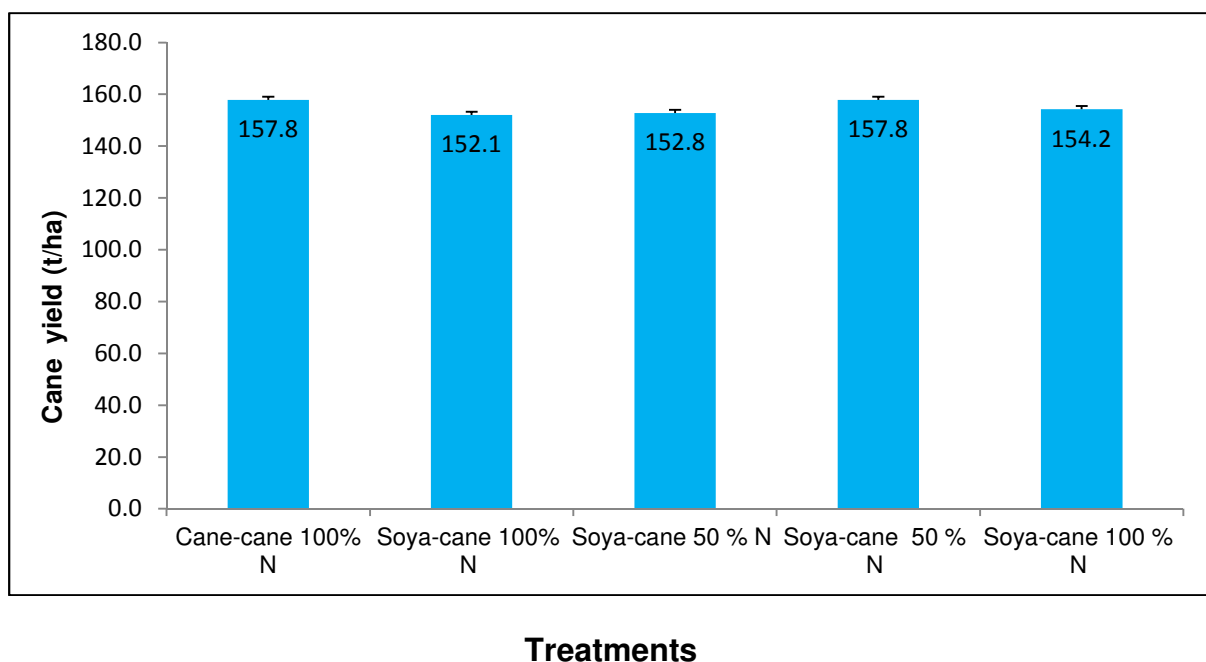


**Figure 5.3:** Sugarcane heights at Bruynshill. Height (cm) was measured on 5 plants per plot in each of the middle two cane rows of each plot. Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soy-cane 100% N (soybean followed by sugarcane with 100% N); soy-cane 50% N (soybean followed by sugarcane with 50% N); soy-cane 50 % N (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soy-cane 100% N (soybean followed by sugarcane with 100% N).

#### 5.4.3.3 Sugarcane yield

At Bruynshill (Figure 5.3), there were no significant differences ( $P>0.5$ ) between the treatments in terms of cane yield. The average yield was 154.9 t/ha, which is below the prediction of 180 t/ha from the Canesim sugarcane model. According to these

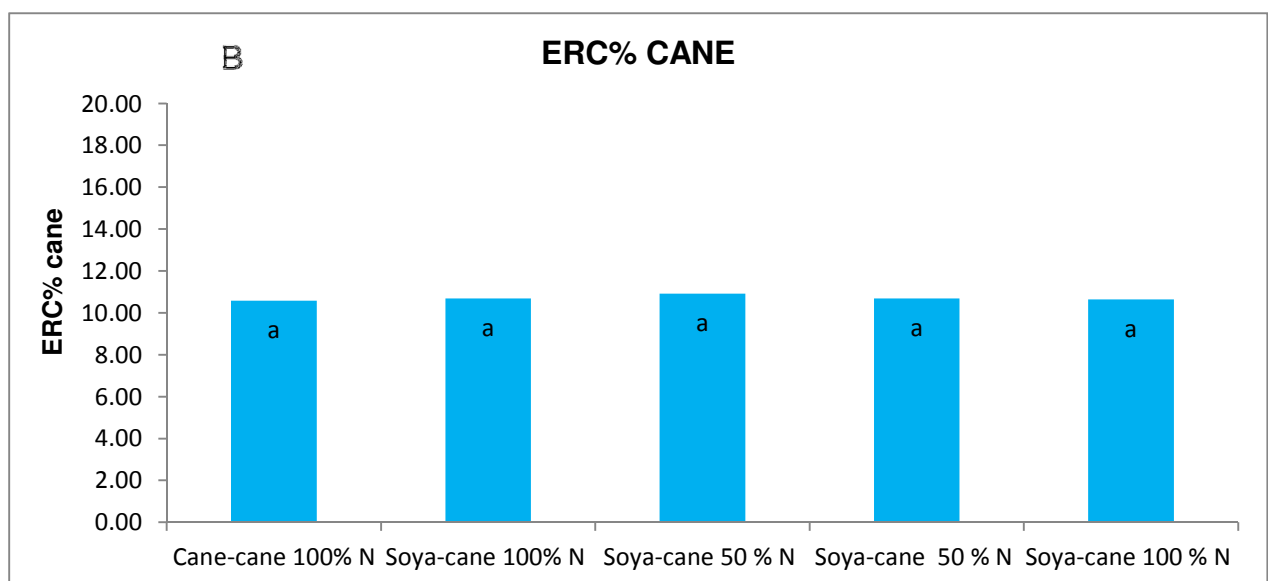
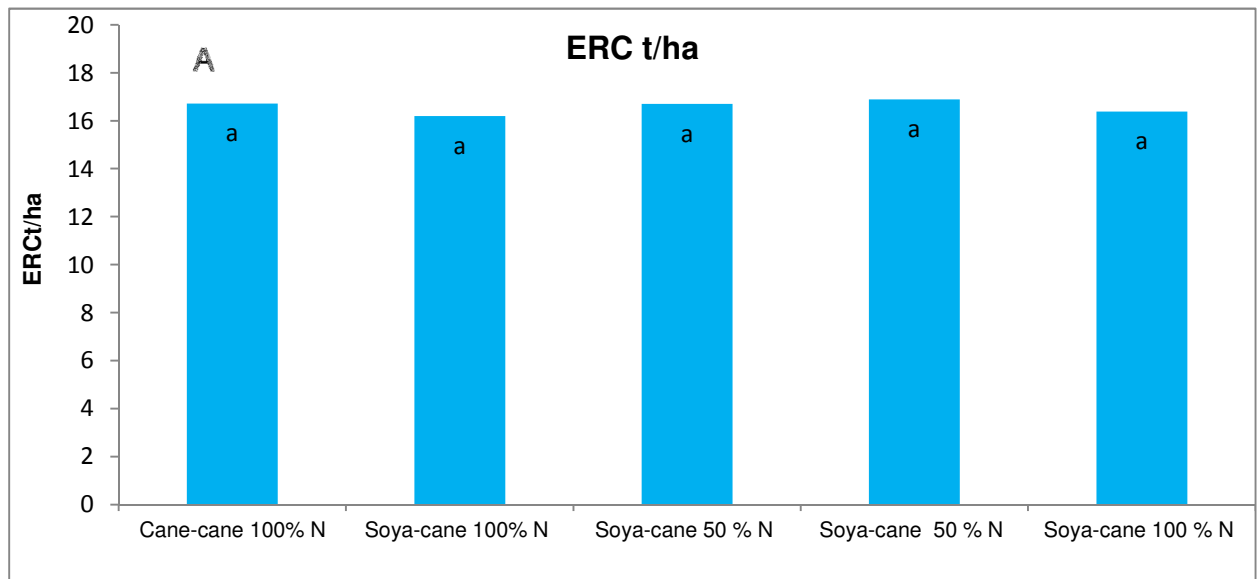
results, rotation of sugarcane with soybeans had no impact on sugarcane yield. Again, this was unexpected based on the findings in international literature, but this result also indicates that the plant crop of sugarcane grown after soybeans can receive up to 50% less N fertilizer applied and produce the same yield as a monoculture system with higher N fertilizer rates. Cane-soya (soybean treated as fodder) indicates that the reduction of N fertilizer by 50% can result the same yield as monocrop with 100%N. Cane-soya with 100%N (soybean treated as green manure) also showed that there was no impact of soybean to sugarcane yield at harvest.



**Figure 5.4:** Sugarcane yield in Bruynshill. Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soy-cane 100% N (soybean followed by sugarcane with 100% N); soy-cane 50% N (soybean followed by sugarcane with 50% N); soy-cane 50% N (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soy-cane 100% N (soybean followed by sugarcane with 100% N).

The data shown in Figure 5.5 illustrate that there was no significant difference ( $P>0.5$ ) between the treatments in terms of ERC% (cane quality) or ERC t/ha

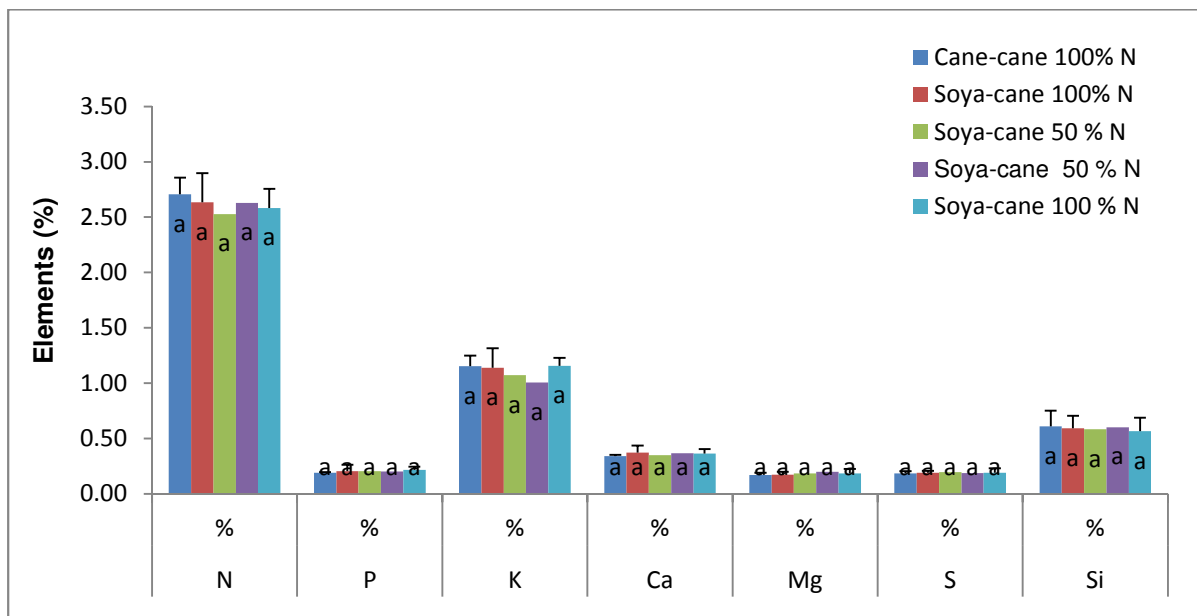
(sucrose quantity). This confirms the same trends as seen in the cane yield data shown above. Similar trends were seen at Mount Edgecombe (chapter 4).



**Figure 5.5:** ERC tons/ha (A) and Estimated recoverable crystal (ERC %) cane (B) at plant crop in Bruynshill trial.

#### 5.4.4 Plant mineral nutrient content, chlorophyll and performance indices

No significant differences in sugarcane leaf N were found between any of the treatments (Figure 5.6). This indicates that N from soybeans had possibly become available to the sugarcane at the 50% N fertilizer level, or that the plant was supplementing its nitrogen from residual N in the soil. No significant differences existed between the treatments for any of the other leaf nutrients either. Cane-soya with 50%N (soybean treated as fodder) and cane-soya with 100%N (soybean treated as green manure) did not show distinct of leaf N compared to cane-soya (soybean grown to harvest). Leaf N results shows that N fertilizer can be reduced by 50% and soybean can be treated differently before sugarcane planting but N on the leaves of sugarcane will not result differently.

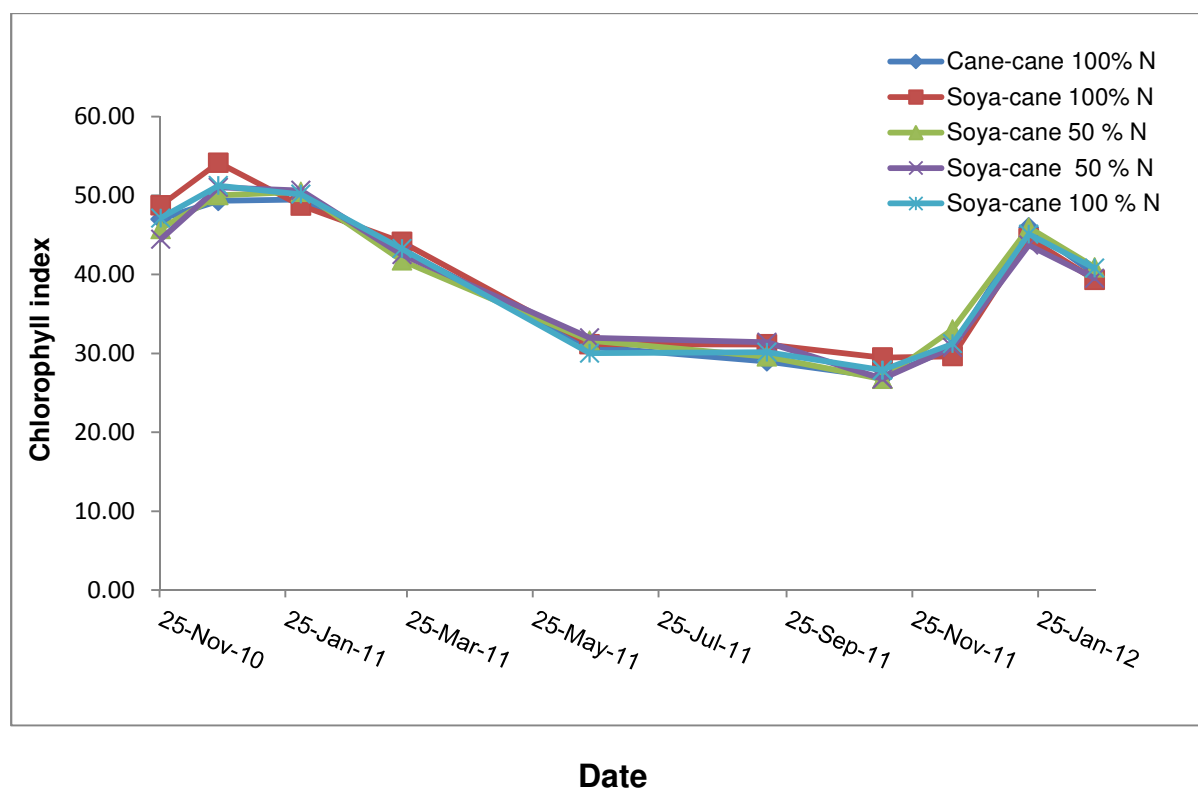


**Figure 5.6:** Sugarcane leaf analysis at 14 leaf growth stage in Bruynshill.

Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soya-cane 100% N (soybean followed by sugarcane with 100% N); soya-cane 50% N (soybean followed by sugarcane with 50% N); soya-cane 50% N (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soya-cane 100% N (soybean followed by sugarcane with 100% N).

#### 5.4.4.1 Chlorophyll content

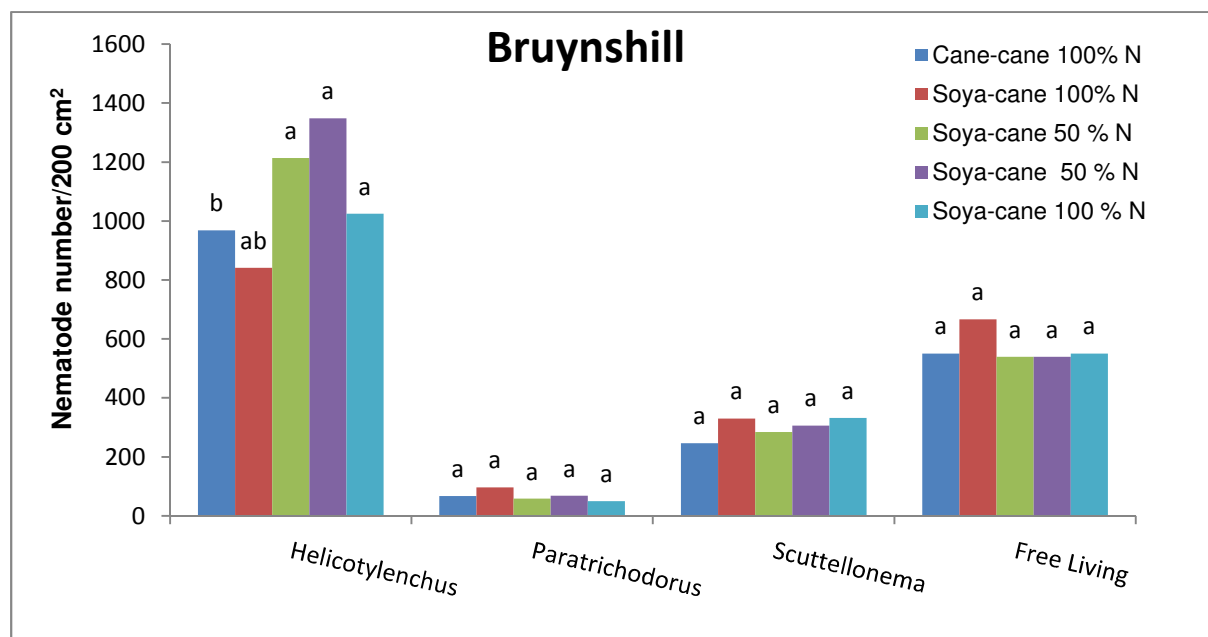
The chlorophyll index showed a similar trend in all treatments including the monocrop control (Figure 5.7), and there were no significant differences between the treatments. Soybean did not appear to increase the chlorophyll index of the sugarcane growing after it. This result was in contrast with Mount Edgecombe. This can be the result of different soils, in Bruynshill soil were sandy. There are many factors which can contribute to the chlorophyll of the plant, e.g. leaching of nutrients from the soil



**Figure 5.7:** Chlorophyll Index at Bruynshill using a SPAD Logger. Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soy-cane 100% N (soybean followed by sugarcane with 100% N); soy-cane 50% N (soybean followed by sugarcane with 50% N); soy-cane 50% N (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soy-cane 100% N (soybean followed by sugarcane with 100% N).

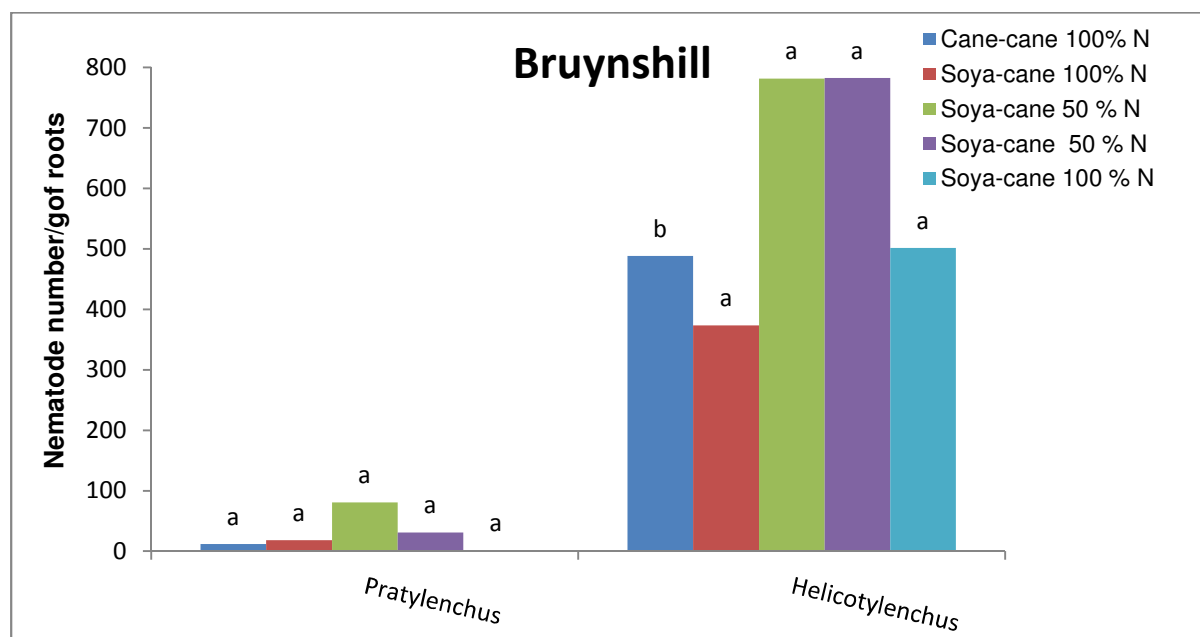
### 5.4.5 Nematode counts in soil and roots

Results from nematode counts performed in soil at harvest of soybeans and termination of the sugarcane control are shown in Figure 5.8. A large diversity of plant parasitic nematodes was found associated with cane. The genera *Pratylenchus*, *Helicotylenchus* and *Scutellonema* were found. Other genera such as *Rotylenchus*, *Hemicyclophora*, *Rotylenchulus* and *Paratrichodorus* were found. Soybeans tended to increase the numbers of *Helicotylenchus* compared to the cane control. These increases were significant at the 5% level. Nematode communities dominated by *Helicotylenchus* are less damaging to sugarcane than communities dominated by other plant parasitic nematodes (Spaull and Cadet, 2003). Free-living (non plant-parasitic) nematode numbers also tended to increase in some soybean plots, although these results were not significant or consistent.



**Figure 5.8:** Nematode populations in the soil at Bruynshill. Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soya-cane 50% N (soybean followed by sugarcane with 50% N); soya-cane 50% N (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soya-cane 100% N (soybean followed by sugarcane with 100% N).

A significantly higher number of *Helicotylenchus* ( $P < 0.05$ ) was observed in the soybean plots (Figures 5.8). Sparkes and Charlestone (2002) also showed that cane following soybean fallows had an impact on plant parasitic nematodes compared to the monoculture of cane-cane. In addition to the reduction in parasitic nematodes after soybean fallows there was an increase ( $P < 0.5$ ) in free-living nematodes which indicates increased biological activity in the soil.



**Figure 5.9:** Nematode population in roots at Bruynshill. Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soya-cane 50% N (soybean followed by sugarcane with 50% N); soya-cane 50 % N (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soya-cane 100% N (soybean followed by sugarcane with 100% N).

## 5.5 Conclusion

Sugarcane leaf samples collected before the plant crop harvest and chlorophyll suggests that N from the soybeans was not being transferred to the sugarcane. At the plant crop harvest, however, there were no significant yield or ERC differences between the different treatments; sugarcane grown after soybeans did not produce higher yields than that grown after cane, nor were the yields significantly suppressed after growing soybeans. Cane-soya (soybean treated as fodder) indicates that the

reduction of N fertilizer by 50% can result the same yield as monocrop with 100%N. Cane-soya with 100%N (soybean treated as green manure) also showed that there was no impact of soybean to sugarcane yield at harvest.

Nematode counts showed that soybeans increased the numbers of the mitigating spiral nematode, *Helicotylenchus*, as well as increasing free-living (non plant-parasitic) nematode numbers  $P < 0.5$ . All of these factors indicate that crop rotation with soybeans has no deleterious effect on the succeeding sugarcane crop and might actually be beneficial to the next sugarcane crop, even if the increase in yields is not immediately visible or measurable. Even though yields didn't increase after soybeans, the non-significant differences between yields indicate that N can be reduced following soybeans and the reduction of application of fertilizer allows a farmer to save up to 50% of his/her N application without yield loss.

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## CHAPTER 6

### THE EFFECT OF SOYBEAN-SUGARCANE CROP ROTATION ON SUGARCANE GROWTH AND DEVELOPMENT ALONG THE NORTH COAST REGIONS OF KWAZULU-NATAL.

#### 6.1 Abstract

Crop rotation is not commonly practised in the sugarcane industry in South Africa. It has, however, proven to be beneficial to other crops in South Africa. The objective of this study was to determine the impact of soybean-sugarcane crop rotation on selected physiological and phenological indicators of cane performance and its subsequent effect on cane and estimated recoverable crystal (ERC) yields. Field trial was conducted at Pongola, where soybean cultivar A5409RG and sugarcane cultivar NCo376 were planted under drip irrigation with different management practices. After the soybean crop, the following sugarcane crop was planted and fertilized with different levels of recommended nitrogen fertilizer (0%, 50% and 100%). The effects on sugarcane growth were recorded by taking into consideration date of emergence, plant height, tiller population, and leaf N. Sugarcane yield and quality at harvest were also evaluated. Tiller population in all crop rotation treatments at Pongola did not performe significantly ( $P < 0.05$ ) better than the monocrop treatment. There was a similar trend from the amount of leaf N in all of the cane-after-soya (crop rotation) crops compared to the cane-after-cane (monocrop) treatments, this was not significant. Sugarcane yield on cane-soya with 0%N was significantly lower than all other treatments including monocrop. ERC% cane and ERC t/ha had no significant difference ( $P < 0.5$ ) which indicate that even if the yield can be reduced but the quality will be maintained. Crop rotation with soybean is beneficial for cane production, but its long term impact on soil quality and farm economy require further investigations.

## 6.2 Introduction

Monoculture is the most commonly used production system worldwide in sugarcane production. This production system leads to a decline in sugarcane yields and depletion of soil fertility (Shoko, *et al.*, 2009).

The rainfed environments of the South African sugar industry are partitioned into three broad regions characterized by different production conditions. However this study only concentrate on the North region which is characterized by areas with low altitude (< 200 m asl), higher temperatures, and high topographic, soil, and rainfall variability. Sugarcane production in South Africa predominantly occurs along the east coast, extending from approximately 25°33'S to 30°93'S and between 29°92'E and 32°32'E, under a diverse range of conditions.

Sugarcane in South Africa is grown in environments that are occasionally not typically conducive to a tropical crop. In South Africa, planting usually occurs in autumn or spring (preferred due to better soil moisture conditions). Germination, tillering, and stalk elongation rates are highly dependent on genotypic and environmental factors (Smit *et al.*, 2004). The crop is harvested when sucrose accumulation within the stalks reaches a peak, and the time to maturity also varies depending on genotype and growing conditions. In South Africa, sugarcane is harvested any time between 12 and 24 months of age, depending on temperatures (influenced by altitude). In the northern production area (where sugarcane is grown under irrigated conditions) and along the coastal belt, harvesting generally occurs at 12-months of age.

Sugarcane requires a summer growing season which is warm to hot, with daily mean temperatures optimally between 22°C and 32°C, together with an abundance of sunshine (> 1200 hours p.a.) and moist conditions. This should be followed by a dry, but sunny and frost-free (only very light frosts tolerated) winter ripening and harvesting period during which Relative Humidity should be < 70%. Little growth takes place at temperatures < 20°C and > 34°C and for sugarcane soil temperatures are as important as air temperatures. Production areas in KwaZulu-Natal are limited

by the July minimum temperature isotherm of 5 °C. The crop does well under a range of soils, but prefers well structured and aerated loams and sandy loam. Sugarcane thrives less well on sandy soils because nematode populations can build up easily, while on clayey soils root development may be hindered. The crop can withstand short spells of waterlogging.

Crop rotation is not commonly practised in the sugarcane industry in South Africa. It has however, proven to be beneficial to other crops in South Africa and for sugarcane production in other countries (e.g. India and Pakistan). Crop rotation with soybean (*Glycine max*) improved maize yields in South Africa by 30 to 50% (Nel, 2005). It has increased sugarcane yield in Australia by 20 to 30% (Garside *et al.*, 1999), with residual effects lasting for several ratoon crops (Garside & Bell, 2007). 2006).

South Africa does not produce enough soybeans to supply current demand and more than a million tonnes are imported annually (AFMA, 2009). Soybean protein is used predominantly for animal feed and the oil is used for edible oil and for bio-fuel. Soybeans have not been grown in the South African sugarcane belt as a cash crop and agronomic research is needed in order to characterise growth behaviour and cropping risks. The objective of the study was to quantify the impact of soybean-sugarcane crop rotation on cane growth and cane yield.

### **6.3 Materials and methods**

Actually experiment details have already been elucidated in chapter 3

### **6.4 Results and discussion**

#### **6.4.1 Soil fertility**

There was a same trend of soil results from Pongola and from the other two trials (chapter 4 and 5) where pH in the soil was reduced and organic matter was increased in the soil after soybean harvest. This indicates that soybean increase

organic matter in the soil and it also reduces pH. Soil sample was taken at soybean harvest from rows and interrows and the results are shown on Table 6.2. Results from the trial indicated that there was no significant difference ( $P>0.05$ ) in any elements after planting soybeans compared to inter-row soil where no soybeans had been planted. The impact of soybean to the soil was less seen at 5 months, differences between row and interrow results maybe seen after a long time from the soil. The results also indicate that soybean add less N to the soil for the incoming crop.

Table 6.1: Pongola soil analysis results before soybean planting.

	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	pH (H <sub>2</sub> O)	Na (ppm)	Clay (%)	OM (%)	NH <sub>3</sub> (%)
0-20 cm	16.2	105.4	675.9	356.1	6.2	7.8	36.4	1.6	3.1
20-40 cm	17.5	105.8	664.6	356.9	6.3	7.8	36.8	1.5	3.0

Table 6.2: Pongola soil analysis results (row and interrow) at soybean harvest.

	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	pH (H <sub>2</sub> O)	Na (ppm)	Clay (%)	OM (%)	NH <sub>3</sub> (%)	P (ppm)
Row	27.70	215.6	656.38	299.18	5.97	7.82	24.85	26.30	1.76	1.88
Interrow	33.81	244.1	657.91	301.96	5.89	7.79	26.54	25.55	1.63	1.80

#### 6.4.2 Performance of soybeans

All soybeans were treated equally at planting, and treatment differences were only imposed at soybean harvest. Soybeans emerged 7 days after planting and took approximately 57 days to flower. Pods were formed 72 days after planting. The average height and aerial biomass at the R5 growth stage of soybeans was 61.8 cm and 6.1 t/ha. According to the ARC Grain Crop Institute (2013), the grain yield was

acceptable for a first time effort (Table 6.6), Moreover some of the stalks were destroyed by termites which also resulted in a very low soybean population at harvest. The soybean height was slightly lower than expected. The 7 to 8% moisture in the soybean grain was unusually low, but the seed dried to below 12%, the upper limit to the acceptable range for mass storage.

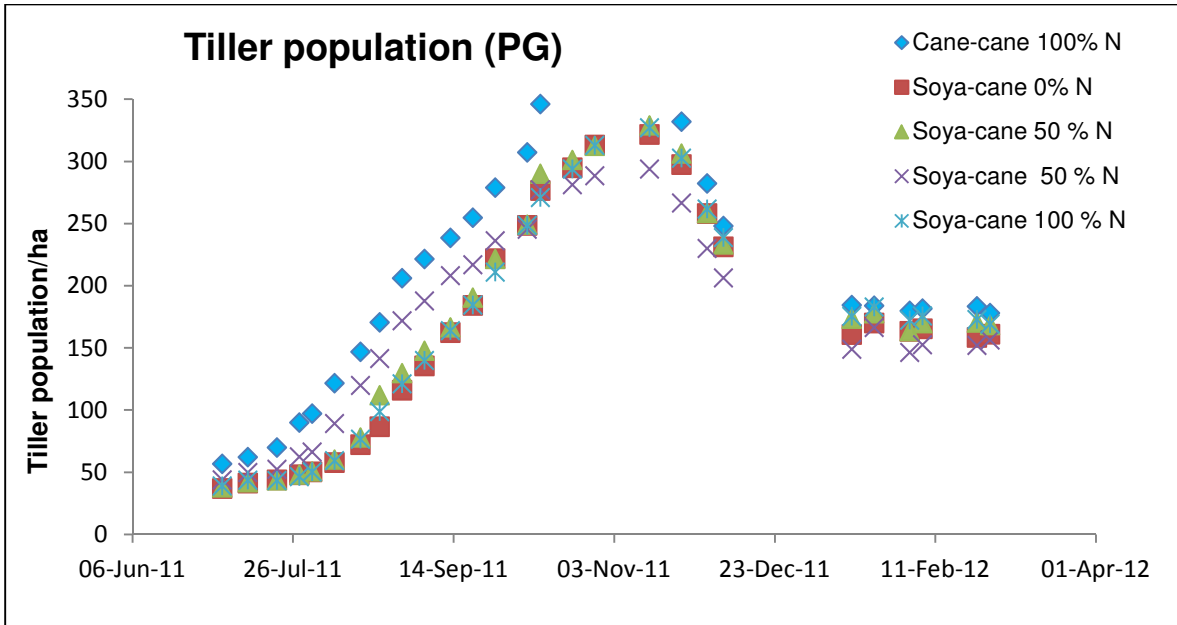
Table 6.3: Soybeans yield for Pongola at harvest.

Site	Grain (t/ha)	Population (stalks/ha)	Height (cm)	Biomass (t/ha)	Grain moisture (%)
<b>PG</b>	2.45	111 904	76.58	6.07	8.57

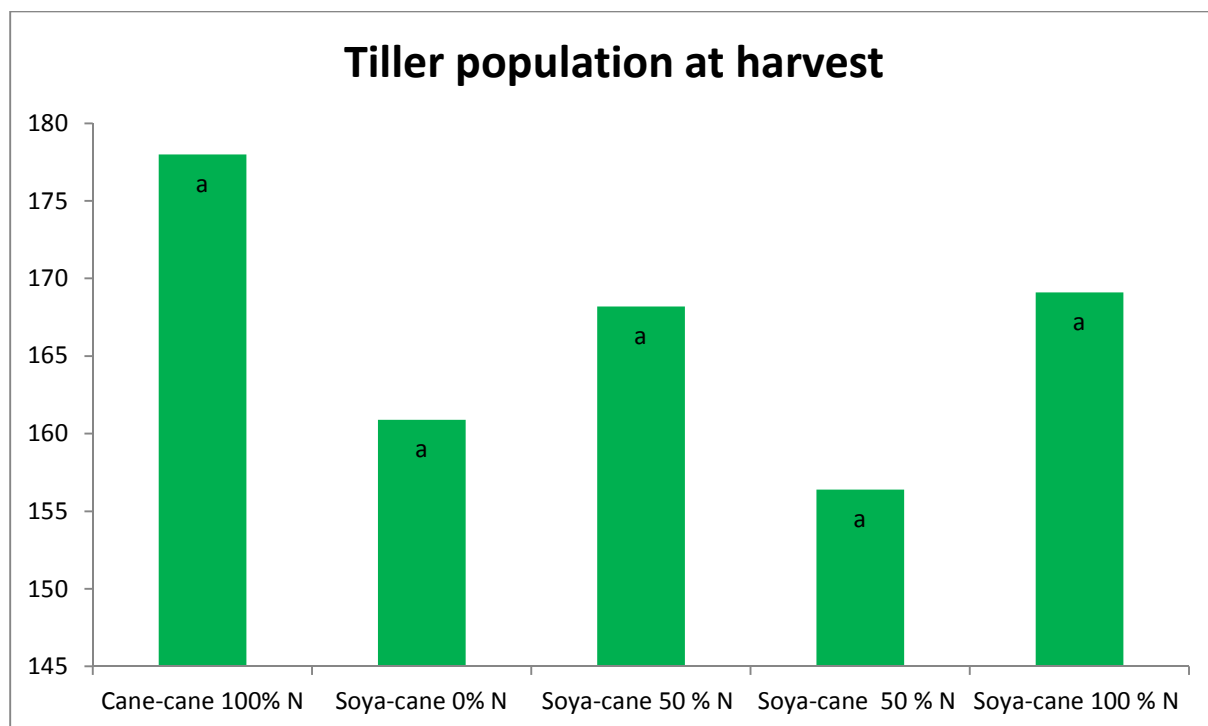
### 6.4.3. Sugarcane crop growth and development

#### 6.4.3.1 Tiller population

At Pongola (figure 6.1), from the time of emergence to the peak tillering, the stalk population was higher in the monocrop than in the crop rotation treatments. After that peak, the monocrop dropped to match that of crop rotation treatments. At the time of harvest monocrop had high tiller number compared to crop rotation treatments. There was a clear trend that soybean declined yields. Interestingly, the 0%N treatment showed a similar tiller population profile as the other rotations, suggesting that excluding N did not affect tiller population dynamics. According to these results, in terms of tiller population the effect of soybeans was not significant ( $P>0.5$ ) by the time of harvest (figure 6.2).

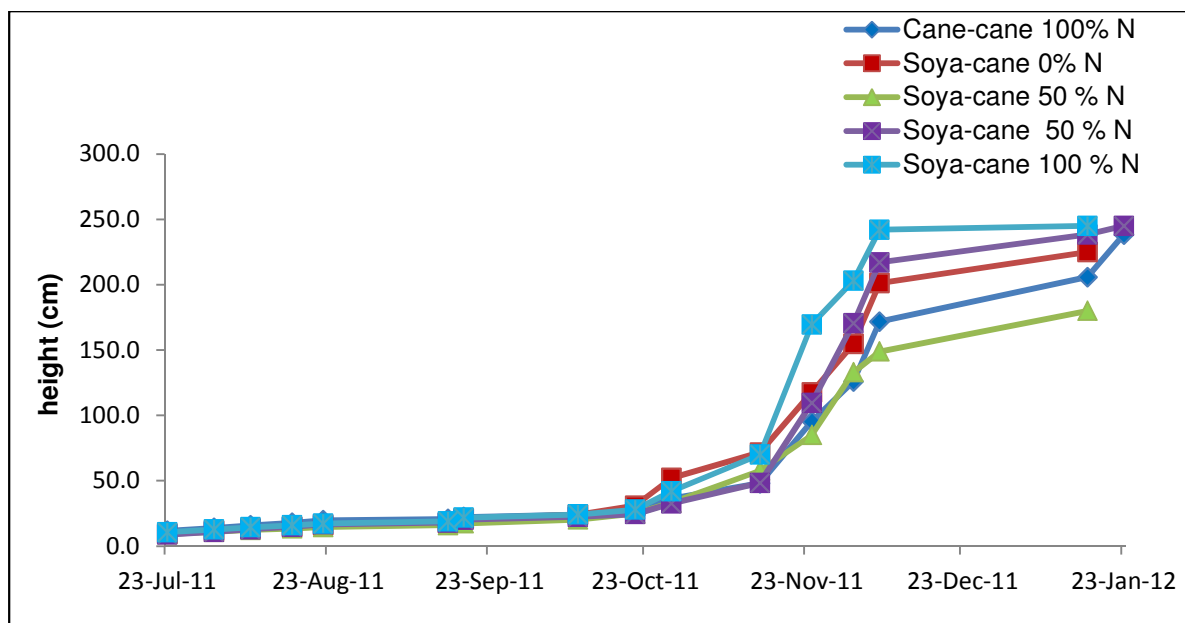


**Figure 6.1:** Tiller population at Pongola. Tiller (stalk) population was measured over 4 m in each of the middle two cane rows of each plot. These counts were then calculated into tiller population/ha as shown in these graphs above. Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soya-cane 100% N (soybean followed by sugarcane with 100% N); soya-cane 50% N (soybean followed by sugarcane with 50% N); soya-cane 50 % N (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soya-cane 100% N (soybean followed by sugarcane with 100% N).



**Figure 6.2:** Tiller population at Pongola. Tiller (stalk) population was measured over 4 m in each of the middle two cane rows of each plot. These counts were then calculated into tiller population/ha as shown in these graphs above. Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soy-cane 100% N (soybean followed by sugarcane with 100% N); soy-cane 50% N (soybean followed by sugarcane with 50% N); soy-cane 50 % N (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soy-cane 100% N (soybean followed by sugarcane with 100% N).

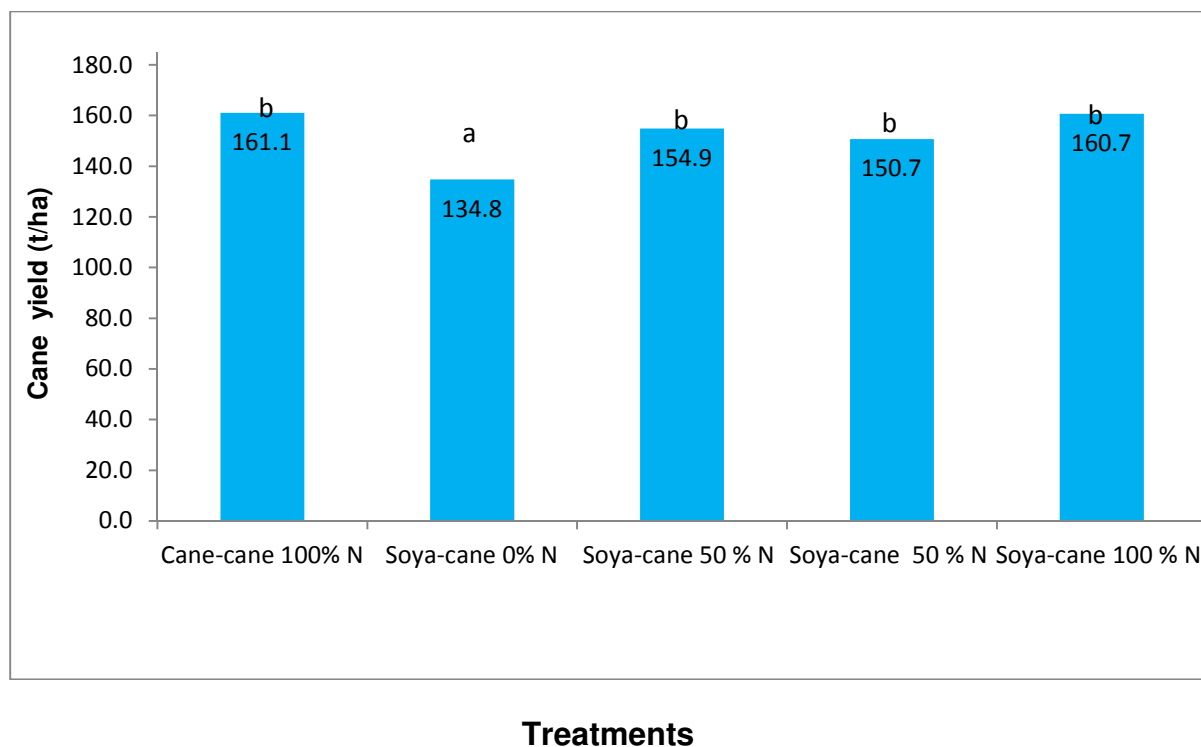
In Pongola (Figure 6.3), there was also a slow stalk extension rate due to the cool season from the time of emergence, and the growth was uniform for all treatments. Once ambient temperatures increased, the extension rate increased, and treatments started to behave differently. The crop rotation treatment with 50% N was the slowest in terms of stalk extension rate, while the crop rotation treatment with 100% N (cane-soya 100% N) had the highest extension rate compared to other treatments, moreover there was no significant difference ( $P>0.5$ ) between the treatments.



**Figure 6.3:** Sugarcane heights at Pongola. Height (cm) was measured on 5 plants per plot in each of the middle two cane rows of each plot. Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soy-cane 100% N (soybean followed by sugarcane with 100% N); soy-cane 50% N (soybean followed by sugarcane with 50% N); soy-cane 50 % N (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soy-cane 100% N (soybean followed by sugarcane with 100% N).

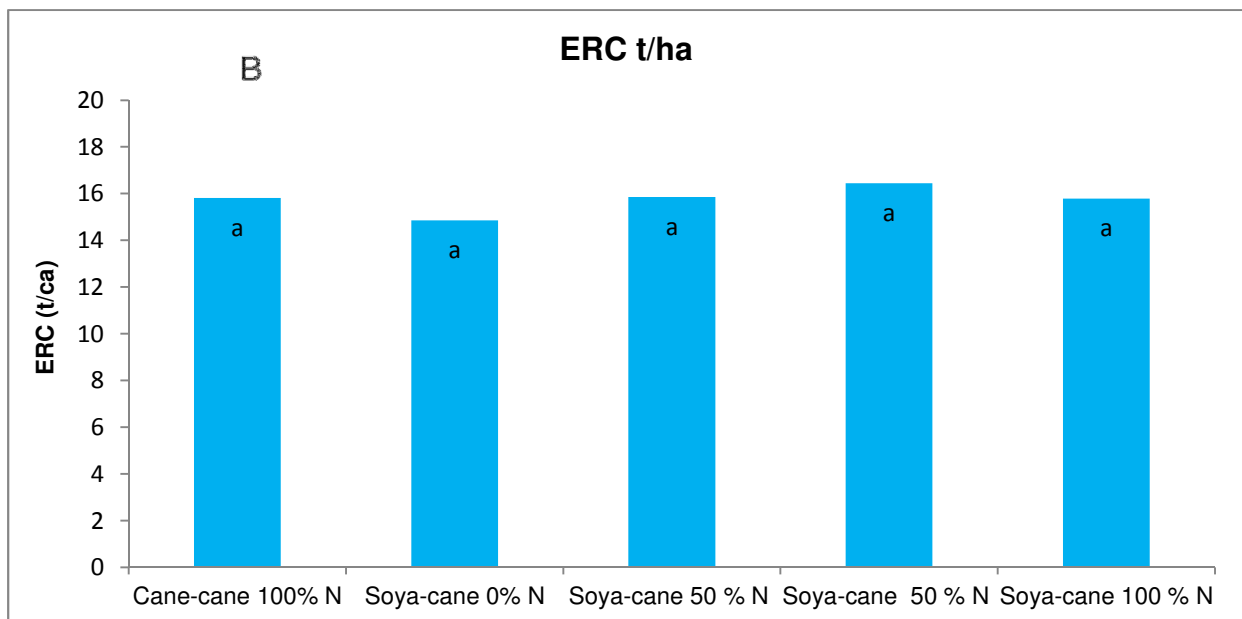
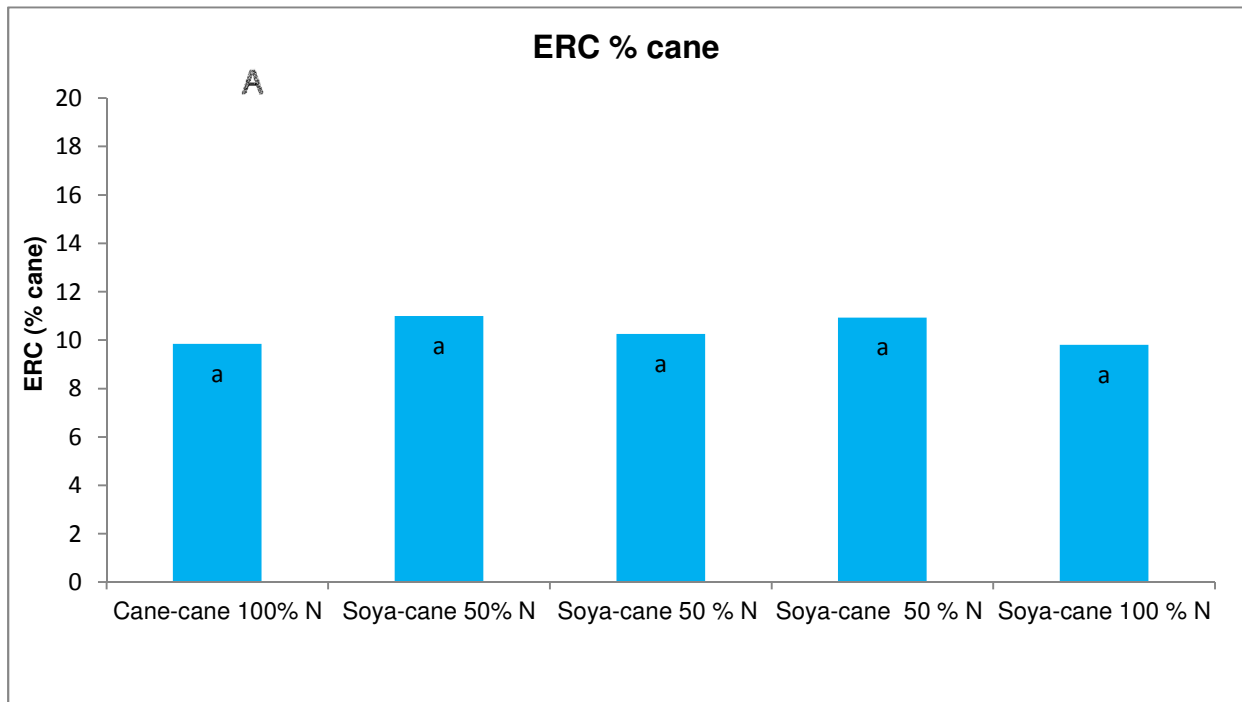
#### 6.4.3.2 Sugarcane yield

At Pongola (Figure 6.4), crop rotation with cane-soya (0% N) was significantly lower ( $P < 0.001$ ) than all other treatments; however, for the other treatments there were again no significant differences in cane yield relative to the monocrop treatment. The application of 50% of the recommended nitrogen fertilizer rate resulted in the same cane yield as that of using 100% nitrogen fertilizer which suggests that the soybeans were able to fix nitrogen and supplement the reduced N fertilizer to support the succeeding sugarcane crop. N in cane stimulates vegetative growth and yields, which reduce sucrose (hence slightly lower ERC% with the N treatments).



**Figure 6.4:** Sugarcane yield in Pongola. Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soy-cane 100% N (soybean followed by sugarcane with 100% N); soy-cane 50% N (soybean followed by sugarcane with 50% N); soy-cane 50% N (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soy-cane 100% N (soybean followed by sugarcane with 100% N).

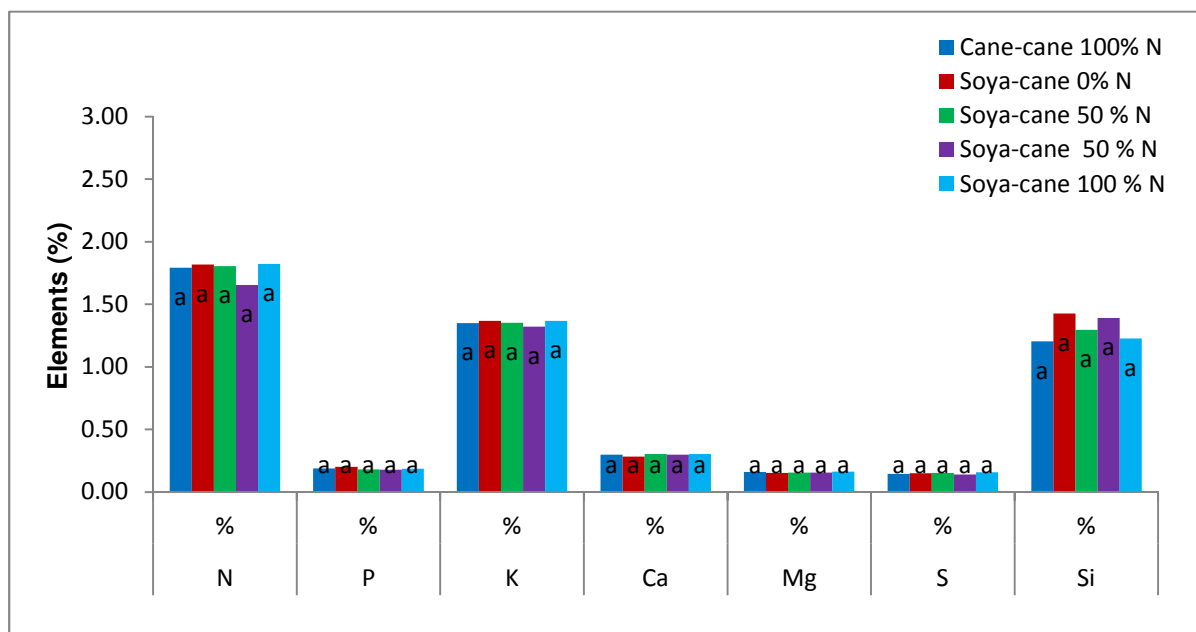
The data shown in Figure 6.5 illustrate that there was no significant difference ( $P > 0.5$ ) between the treatments in terms of ERC% (cane quality) or ERC t/ha (sucrose quantity). This is different from yield where cane planted after soya with 0% N was significant low ( $P < 0.001$ ) in terms of yield compared to all fertilized treatments. Low yield or high yield did not affect the cane quality. N in cane stimulates vegetative growth and yields, which reduce sucrose (hence slightly lower ERC% with the N treatments).



**Figure 6.5** Estimated recoverable crystal (ERC %) cane (A) and tons ERC /ha (B) for the plant crop at the Pongola trial.

#### 6.4.4 Plant mineral nutrient content, chlorophyll and performance indices

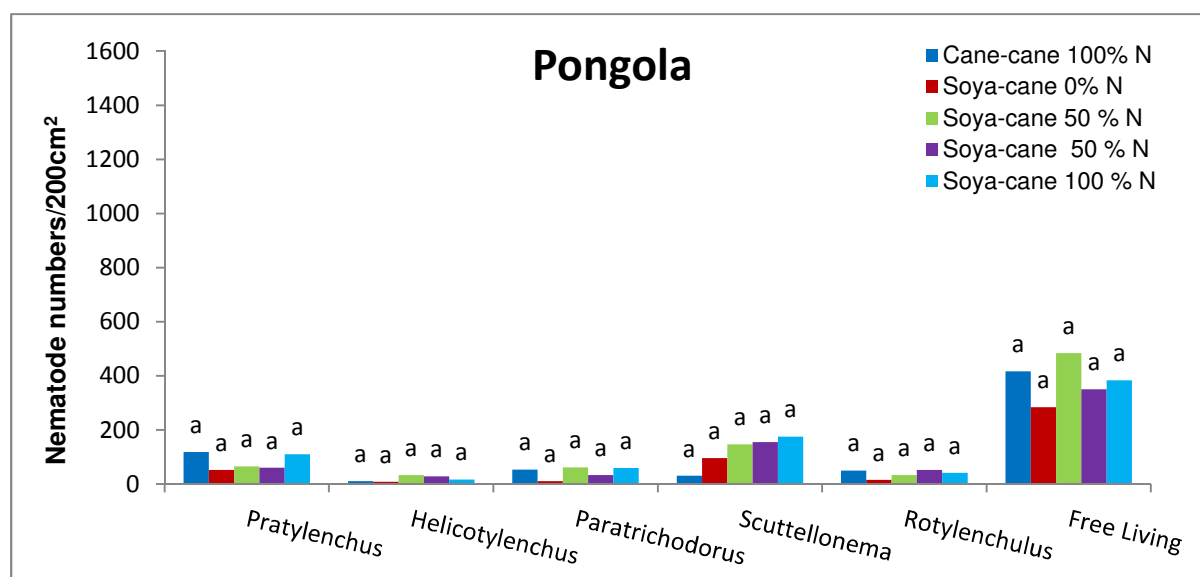
Leaf N in all four cane-after-soya treatments showed no significant differences compared to the cane-after-cane ‘monocrop’ treatment for Pongola (Figure 6.6). This indicates that N from soybeans was being transferred to sugarcane at both levels of N fertilizer (0 and 50 % N), or that the plant was supplementing its nitrogen from residual N in the soil. The same is true for the other chemical elements measured in the leaves i.e. no significant difference ( $P < 0.5$ ) between the treatments. Cane-soya 50%N (soybean grown to harvest) and cane-soya 50 and 100%N (soybean treated as fodder and green manure) did not show any dramatic change in terms of N on sugarcane leaves as expected. Soybean nodules were expected to capacitate N for sugarcane.



**Figure 6.6:** Sugarcane leaf analysis at 14 leaf growth stage in Pongola Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soy-cane 100% N (soybean followed by sugarcane with 100% N); soy-cane 50% N (soybean followed by sugarcane with 50% N); soy-cane 50 % N (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soy-cane 100% N (soybean followed by sugarcane with 100% N).

## 6.4.5 Nematode counts in soil and roots

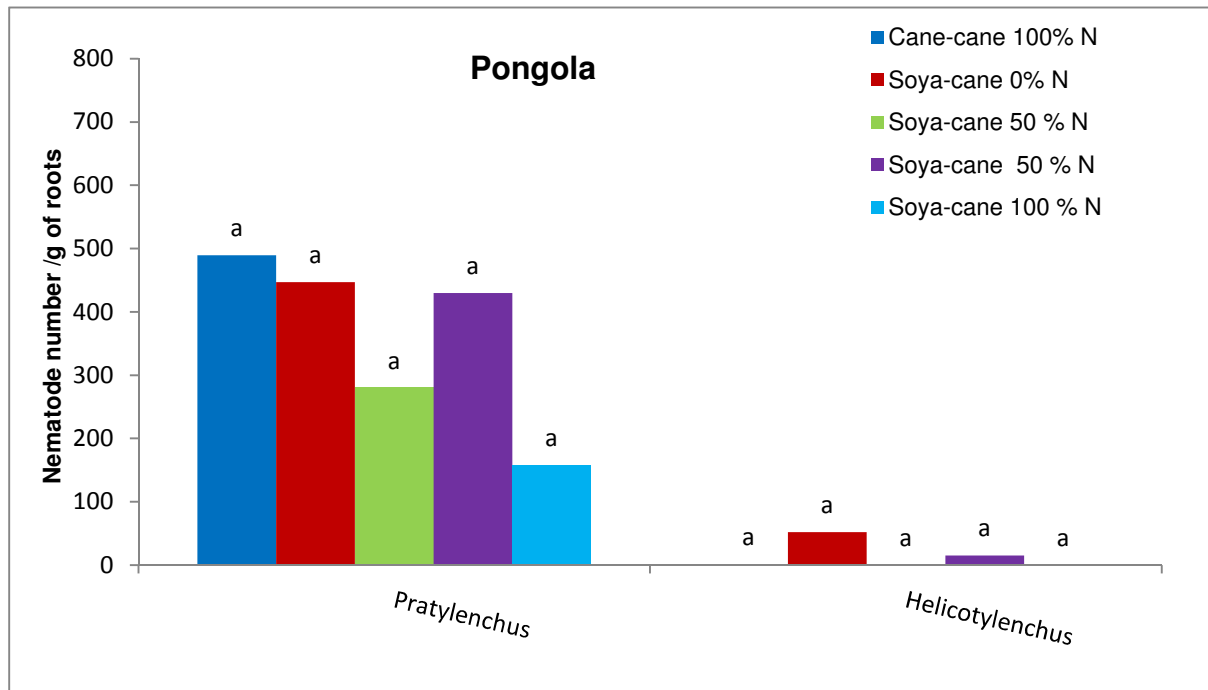
Results from nematode counts performed in soil at harvest of soybeans and sugarcane are shown in Figure 6.7. A large diversity of plant parasitic nematodes was found associated with cane. The genera *Pratylenchus*, *Helicotylenchus* and *Scutellonema* were found. Other genera such as *Rotylenchus*, *Hemicycliophora*, were also found at Pongola trial site. There were no significant differences ( $P>0.5$ ) in nematode counts in the soil. Free-living (non plant-parasitic) nematode numbers also tended to increase in the soybean plots, although these results were not significant or consistent.



**Figure 6.7:** Nematode populations in the soil at Pongola. Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soya-cane 50% N (soybean followed by sugarcane with 50% N); soya-cane 50 % N (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soya-cane 100% N (soybean followed by sugarcane with 100% N).

Results from nematode counts performed on roots at harvest are shown in Figure 6.8. The genera of *Pratylenchus* and *Helicotylenchus* were found, however

*Pratylenchus* were high on the roots but there was no significant difference ( $P < 0.5$ ). Sparkes and Charlestone (2002) also showed that cane following soybean fallows had an impact on plant parasitic nematodes compared to the monoculture of cane-cane.



**Figure 6.8:** Nematode population in roots at Pongola. Treatments were: cane-cane 100% N (sugarcane followed by sugarcane with 100% N applied); soy-cane 50% N (soybean followed by sugarcane with 50% N); soy-cane 50% N (soybean with fodder (biomass) removed followed by sugarcane with 50% N); soy-cane 100% N (soybean followed by sugarcane with 100% N).

## 6.5 Conclusion

At the plant crop harvest, yield on cane-soya (0%N) was significantly low compared to all other crop rotation and monocrop treatments. Sugarcane yield from crop rotation treatments were not significant ( $P < 0.5$ ) high compared to monoculture. ERC% cane and ERC t/ha had similar trends (no significant difference  $< 0.5$ ) in all treatments) indicating that low or high yields did not affect sugarcane quality.

All of these factors indicate that crop rotation with soybeans has no deleterious effect on the succeeding sugarcane crop and might actually be beneficial to the next sugarcane crop, even if the increase in yields is not immediately visible or measurable. Even though yields didn't increase after soybeans, the non-significant differences between yields indicate that N can be reduced following soybeans and the reduction of application of fertilizer allows a farmer to save money for 50% N which was spent during monocropping.

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## CHAPTER 7

### A PRELIMINARY ECONOMIC ANALYSIS OF SOYBEAN-SUGARCANE CROP ROTATION SYSTEM

#### 7.1 Abstract

Growing legume fallow crops has proven to be an important factor in minimising the yield decline in sugarcane production. The objective of this study was to determine the economics of a cane-on-cane monoculture farming system vs. crop rotation with soybeans farming system. A field trial was conducted in Pongola where soybean cultivar A5409RG and sugarcane cultivar NCo376 were planted under drip irrigation with different management practices. After the soybean crop, the following sugarcane crop was planted and fertilized with different levels of nitrogen fertilizer (0%, 50% and 100%). Farm economic analysis to determine the differences in gross margin between monoculture and crop rotation was conducted. The new system reduced the amount of fertiliser application by 50% in the plant crop and produced the same yield as the monoculture where 100% nitrogen fertiliser had been applied. The yield was significantly ( $P < 0.001$ ) reduced with zero N. Cost of nitrogen fertiliser was also reduced due to the fact that the sugarcane yield from 50% nitrogen fertiliser and 100% nitrogen fertiliser applied on sugarcane monoculture was not significantly different ( $P > 0.5$ ). The reduction in sugarcane growing cost from R16 805.41 to R15 939.00 per ha was calculated. The soybean crop grown for seed production was also found to provide additional income with a gross margin of R4 502.56/ha. The other difference in the new system was the reduced number of hours spent on tractors (reduction from 2.49 to 2.18 hrs/ha). The improvement in returns with the crop rotation system was a result of lower variable costs and additional revenue from the soybean crop rotation.

## 7.2. Introduction

Growing legume fallow crops has proven to be an important factor in reducing the yield decline effect common in long-term sugarcane production systems (Garside *et al.*, 1999). Rotation of sugarcane with soybean provides both a source of fixed nitrogen and improvement in soil health (Garside *et al.*, 1998). Legumes can also provide a direct economic benefit, in some instances; income can flow from the sale of grain or seed. A partial budget was prepared to assess the impact of the new farming system (crop rotation system) on farm profitability. This case study may assist commercial growers in their decision to change to a crop rotation system, by evaluating whether the cost of new implements and management are economically justified. When evaluating a farming system change, it is important to have a detailed plan and an accurate assessment of benefits and costs involved for your own situation. This case study focused on the economics of a cane-on-cane monoculture farming system versus a crop rotation system of soybeans with sugarcane.

## 7.3 Farming systems

Having considered the trials discussed in chapter 3 above, where three trials were conducted at three different sites (Mount Edgecombe, Bruyns Hill and Pongola) in KwaZulu-Natal, South Africa; for the purposes of this chapter, only the results from the Pongola trial were considered. Roundup-Ready soybean cultivar (A5409RG) was planted under irrigation. The soybeans were followed by sugarcane (variety NCo376) planted with different levels of nitrogen fertilizer (0%, 50% and 100% of the recommended fertiliser N rate). A cane-on-cane control was used for comparison.

Table 7.1 shows the differences in farming practices between the 'old' (monoculture) and 'new' (soybean crop rotation) farming systems in the trial. The major differences in the new system are the reduced tractor machinery operations and the addition of a soybean fallow crop for seed production. In KwaZulu-Natal, soybeans are planted in November and harvested in April, and then sugarcane can then be grown from May onwards. This system allows a farmer to produce an income during the fallow period

and permanent workers will most likely be employed since they will be no “off-season”.

Table 7.1a: Comparison between management inputs associated with the ‘old’ (monoculture) and ‘new’ (soybean-cane crop rotation) farming systems.

	<b>Monoculture</b>	<b>Crop rotation system</b>
Land Preparation following final cane crop	Sugarcane Land Preparation: Mouldboard plough Disk plough	Soybean Land Preparation: Mouldboard plough Disk plough
<i>Soybean planting method</i>		Soybean planter Soybean seeds & inoculant was purchased (*zero N applied; assume that any P or K application can be offset against later applications to the cane)
Weed control (during soybean crop)		Roundup 263 ml in 15 L of water (3.5 L/ha); Metribuzin 47 ml (0.25 L/ha); Falcon 188 ml (1.0 L/ha) in 15 L of water. Velocity 69 ml (2 L/ha)
Insect control (during soybean crop)		Immoboost (300 ml), Fastac 4 ml (0.1 L/ha) per 15L water.
Disease control (during soybean crop)		Punch Extra 21 ml (0.6 L/ha) in 15 L of water (for rust control).
Soybean harvesting		Combine harvester Transport to silo

Table 7.1b: Comparison between management inputs associated with the 'old' (monoculture) and 'new' (soybean-cane crop rotation) farming systems.

<i>Sugarcane Planting method</i>	Ridge and plant sugarcane	Ridge and plant sugarcane
<i>Fertilizer - sugarcane</i>	Superphosphate (40 kg/ha), Potassium chloride 200 kg/ha at planting and 140 kg N/ha (as urea) top dressed on cane-cane 100% N and soya-cane 100% N (2)	Superphosphate (40 kg/ha), Potassium chloride (200 kg/ha) in all treatments at planting and 70 kg/ha N (as urea) top dressed on soya-cane 50% N (1) and soya-cane 50% N (2) and soya-cane 0% N received 0 kg/ha N.
<i>Weed Control</i>	Chemicals Cane sprayed with 47 ml (0.25 L/ha) Metribuzin +188 ml (1.0 L/ha) Falcon in 15 L of	Chemicals Cane sprayed with 47 ml (0.25 L/ha) Metribuzin +188 ml (1.0 L/ha) Falcon in 15 L of water
<i>Irrigation</i>	Drip irrigation, same costing used in monocrop and crop rotation system	Drip irrigation, same costing used in monocrop and crop rotation system
Cane Harvesting & Transport costs		No significant difference between the 50% N and 100% N yields, but 0% N had significantly lower yields without the tons ERC being lowered. This means that the grower would have saved the N costs, had lower tonnage to cut and transport, without getting reduced income.

There is very little additional land preparation for the new system compared to the monoculture, because all operations which are conducted when monoculture is practised are also practised during the new system, the only addition being planting of the soybean seeds. The new system reduced the amount of fertilizer application by 50% (or potentially 100% in the plant crop) and produced the same yield as the monoculture where 100% nitrogen fertilizer had been applied (though yield was significantly reduced with zero N). This indicates that soybean is beneficial to the sugarcane crop, by fixing nitrogen for the next crop. Soybean grain yield can also result in extra income to the farmer. The new system also potentially introduces less tangible benefits such as improved plant performance; soil health improvement and a reduction of plant-parasitic nematodes in the sugarcane and an increase in free-living nematodes showing that there is increased biological activity in the soil (see Chapter 4 in this dissertation).

Variable costs are based on details such as rates of chemical application, kilograms of fertiliser and machinery operations for a particular crop class. Machinery operating costs are based on the tractor size, fuel consumption, implement speed, width, field efficiency and repairs and maintenance. Calculations of the tractor and irrigation labour required for each farming system are based on the work rate for each operation. Comparison of historical (monocrop) farming system to the 'new' (crop rotation) farming system by applying current input prices to each scenario give a clear indication of the value of each system. The same commodity price is applied to both systems. This approach shows what the return on investment would be today, comparing the old and new systems.

#### **7.4 Farm economic analysis: monoculture vs. crop rotation**

Monoculture and crop rotation system showed no differences in sugarcane yields but the crop rotation system proved that reducing the amount of nitrogen fertiliser by 50% resulted in the same yield as 100% N monoculture (Table 7.2). This indicated that planting sugarcane after soybean can reduce the cost of nitrogen fertiliser by half. The number of hours spent on tractors in the cane monocrop operation was reduced from 2.49 to 2.18 hrs/ha (Table 7.2). The reason for the decline in the

tractor hours in sugarcane monoculture was due to less cultivation operations and part of the tractor operation time being allocated to preparing the land for soybeans.

Table 7.2: Economic comparison of two farming systems and tractor hours.

	<b>Monoculture</b>	<b>Crop rotation treatments</b>
Average yield cane	Cane-cane 100% N 161.1 b	Cane-soya 0% N 134.8a Cane-soya 50% N (1) 154.9 b Cane-soya 50% N (2) 150.7 b Cane-soya 100% N (2) 160.7 b
Tons ERC/ha	Mono +100%N 15.8	Cane-soya 0% N 14.9 Cane-soya 50% N (1) 15.9 Cane-soya 50% N (2) 15.8 Cane-soya 100% N 2) 15.8
RV price/t	R 3 163.78	R 3 163.78
Price per ton sugar	R352.38	R352.38
Cane tractor labour hours/ha	2.49	2.18

Table 7.3: Cost of growing cane per hectare (whole farm).

	<b>Monoculture (R/ha)</b>	<b>Crop rotation (R/ha)</b>
Land Preparation	2 337.90	1 530.60
Planting + Seed	7 240.20	7 240.20
Fertiliser , Soil Ameliorants	1 606.60	1 547.49
Weed Control	1 440.09	1 440.09
Irrigation	4 180.62	4 180.62
<b>Total Growing Cost</b>	<b>16 805.41</b>	<b>15 939.00</b>

Table 7.4: Soybean gross margin.

<b>Price</b>	R 4 622.98/t
<b>Payment Yield</b>	2.5 t/ha
<b>Gross Income</b>	<b>R11 557.45</b>
<b>Expenses</b>	<b>R/ha</b>
Land preparation	2 197.86
Planting	1 013.17
Weeding control	1 070.79
Disease control	455.59
Insects control	189.03
Irrigation	1 723.65
Harvesting	404.81
<b>Total variable expenses</b>	<b>R 7 054.89</b>
<b>Gross margin per hectare</b>	<b>R 4 502.56</b>

The improvement in returns with the crop rotation system is a result of lower variable costs and additional revenue from the soybean crop rotation. Table 7.4 shows the reduction in cane growing cost from R16 805.41 /ha (monocrop system) to R15 939.00 /ha (crop rotation system). The soybean crop grown for seed production also provides additional income with a gross margin of R4 502.56/ha (Table 7.5).

## **7.5 Conclusion**

Economic analysis comparing a soybean crop rotation system with sugarcane monoculture showed that the cost of land preparation was reduced simply because other activities took place during soybean preparation. A gross margin of R4 502.56per hectare showed that soybeans can prove a good cash crop during the normal fallow period. In addition, there are other benefits such as a reduction in time spent by the tractor operator per hectare during sugarcane period planted after soybeans.

Rotation of soybean and sugarcane is economically viable since production costs of sugarcane are reduced in this system. Rotation system can improve sustainability of sugarcane as it requires less input for stable crop yield.

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## CHAPTER 8

### GENERAL DISCUSSION AND CONCLUSIONS

Crop rotations are fundamental to sustainable cropping systems. Crop rotation between sugarcane and soybeans should be adaptable to the existing soil, climatic and economic factors. The work in this thesis was based on the hypothesis that planting sugarcane after soybean could be beneficial. Firstly, an investigation into how well or poor soybeans grew in traditional sugarcane growing areas and soil was studied when soybeans were planted before sugarcane crop in three trial sites (Mount Edgecombe, Bruynshill and Pongola).

It was noted that growth, development and yield of soybeans are a result of a variety's genetic potential interacting with environment and farming practices. Correct production decisions using plant growth staging and timing are important for successful soybean production. According to the yields obtained (average soybean grain yield of 2.5 t/ha) obtained over the three trials, there is potential for soybean production in KZN, however, there are various issues to be considered when planting soybean for the first time, particularly as soybeans require more management compared to traditional sugarcane cultivation.

There was a same trend from all trials where organic matter was increased and pH was reduced in the soil after soybean was planted. In all three trials during soybean growth weeds were reduced due to the fact that soybean canopy closes rapidly limiting the opportunity for weeds to grow. Once the soybeans mature and start to drop their leaves the canopy opens and weeds become established. Traditionally growers have used cultivation at this stage, however there were less weeds in three trials and this allowed a weed free area for sugarcane planting.

Growing soybean is considered to be a lot more effort in having to prepare a finer seedbed, gain access to a planter and having to spend money on weed control. The

fallow crop is always considered in isolation and not as part of the whole system. Many growers would now realise that investing money in the fallow can pay dividends; with 50% nitrogen topdressing required in the plant cane, less expensive weed control because pre emergence weeding is not considered on cane due to preceding soybeans, in the cane crop as well as soil health benefits and the opportunity to reduce tillage in the cane crop. Even though the soybean crop has its benefits, the sugarcane farmer will always have to invest in new implements to accommodate all soybean operations. A planter and a combine harvester must be available for planting and harvesting of soybeans (Poggio and Young, 2007); these implements can either be owned or hired.

Sugarcane was planted after soybeans and all growth phases were evaluated. Sugarcane leaf samples taken before the plant crop harvest, chlorophyll and plant performance index was not clear whether N from the soybeans was possibly transferred to the sugarcane crop because, the study did not look at the amount of nitrogen transferred from soybeans to sugarcane. This could be part of a future study. Tiller population from different trials showed the same trend and there were no significant differences. Tiller population indicated that even if N fertilizer can be reduced by 50% but farmers can receive the same yield as 100% N. Cane-soya (soybean grown to harvest and soybean treated as green manure) had the same tiller population. Surprisingly, in Pongola 0%N also resulted the same trend with all other treatments. This was indication that N did not affect tiller population. Height in all trials did not have any significant difference. Stalk extension on cane-soya with 100%N (soybean grown to harvest and soybean treated as green manure) had the same trend. However sugarcane height on treatment 3 (cane-soya with 50%N, soybean grown to harvest) grew slow compared to all other treatments in all trials. At the plant crop harvest, there were no significant yield or ERC differences between the different treatments; sugarcane grown after soybeans did not produce dramatically higher yields than continuous cane.

Nematode counts showed that soybeans had increased numbers of the mitigating spiral nematode, *Helicotylenchus*, at Mount Edgecombe, Bryunshill and Pongola as well as increasing free-living (non plant-parasitic) nematode numbers. In Mount

Edgecombe, in particular, the plant-parasitic lesion nematode *Pratylenchus* was decreased significantly by the soybeans, in comparison to the cane plots and this is one of the benefits of using crop rotation between soybeans and sugarcane. Research done in Australia has shown that the use of soybean as a break crop reduced the population of the root knot, lesion and cyst nematodes compared to monoculture sugarcane production (Bell *et al.*, 2001b).

Economic analysis on a soybean crop rotation system with sugarcane monoculture showed that cost of land preparation was reduced simply because other activities took place during soybean preparation and this was also demonstrated by Young & Poggio (2007). Cost of nitrogen fertilizer was also reduced due to the fact that the 50% reduction of nitrogen fertilizer on crop rotation treatment resulted in the same yield as 100% of nitrogen fertilizer for sugarcane monoculture. Despite low production cost of soybeans, a gross margin of R4502.56 per hectare showed that this is a good cash crop during the normal fallow period. In addition, there are other benefits such as a reduction by 31 minutes time spent by tractor labour per hectare during sugarcane period planted after soybeans. This new system can help farmers to increase and diversify income sources by having an alternative option to shifting cultivation. It is possible to plant sugarcane after soybeans because most of the activities which are taking place during soybean period have a positive effect on sugarcane.

The major weaknesses of this study are:

1. The effect of soybean crop rotation on sugarcane ratooning was not investigated. It has been mentioned in this dissertation that crop rotation with soybean results in a residual effect lasting for several ratoon crops (Garside & Bell, 2007). Unfortunately, this could not be measured in the duration of our trials due to the work only being commissioned for two years.
2. As mentioned in Chapter 3, soybean as a cash or green manure crop can only be planted from November onwards. The succeeding sugarcane crop can then be planted from April/May onwards the following year. Thus

sugarcane that is planted in the autumn can benefit from this rotation system. However, this does not help sugarcane planted in spring or summer, unless perhaps the soybean rotation is followed by another crop rotation of a suitable winter green manure crop (e.g. oats) before planting to sugarcane again in Spring or Summer. However, the residual benefit to sugarcane after oats-soybean rotation has not yet been determined. A double rotation of two crops (legume in summer followed by oats in winter) will extend the crop rotation effect from 6 months with soybean only to approximately 12 months with both crops. Berry *et al.*, (2012) showed that the beneficial effect of green manuring is magnified the longer the crop rotation sequence increases.

## 8.1 Recommendations

For future studies it is recommended that studies should be done on:

1. Determining the amount of nitrogen transferred by soybean to sugarcane.
2. Determine sugarcane yield differences in ratoon crops of sugarcane. It is suggested that there be ratooning trials for at least 3 ratoon crops. Sometimes crop differences only become noticeable the longer you ratoon the crops. Particularly since often nutrient deficiency trials only start showing major differences in growth compare to the control from 2<sup>nd</sup> ratoon onwards (Rhodes *et al.*, 2012).
3. Determining soil change from each and every ratoon on crop rotation vs. monoculture.

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